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HIGH-TEMPERATURE MATERIALS FOR GAS TURBINES *page* 116

(Iron and Steel Institute Symposium)

Page

General

Investment Casting of Nickel-containing Materials: Study of Pre-Coats 128
Machining of Nickel and Nickel-containing Materials 128
Brazing of Nickel-containing Materials 128

Nickel

Production of Nickel-Clad Steel by Lukens Steel Company 129
Spectrophotometric Analysis of High-Nickel Alloys 129
Determination of Nickel in Effluents 129
Determination of Nickel in Calcium 130
Alpha-Furildioxime as Reagent for Determination of Nickel 130

Electrodeposition and Other Coating Methods

Cleaning of Metals Prior to Electroplating: A.E.S. Research Project 130
Modern Electroplating Plant 130
Nickel Plating in the U.S.A.: Review 131
Nickel Plating of Aluminium and its Alloys 131
Commercial Plating of Automobile Parts 131
Conservation of Nickel Salts in Nickel-Dip Process 131
Corrigendum 132

Non-Ferrous Alloys

Properties of Age-Hardening Nickel-base Alloys 132
Nickel Additions in Copper-base Alloys 133
Monel Stays in British Railways Standard Locomotives 134
Nickel-Manganese-Silicon Sparking-Plug Alloys 134

Nickel-Iron Alloys

Thermal Expansion of Invar: Influence of Impurities 134
Nickel-Iron Alloys in Inductive Loading Devices in Telephones 135

Page

Cast Iron

Isothermal Transformations in Nickel-containing White Cast Iron 135
Spheroidal-Graphite Cast Iron: Current Stage of Development 136
Machinability Tests on Spheroidal-Graphite Cast Irons 136
Nickel-Alloy Cast Iron in Crankshafts 137
Determination of Magnesium in Cast Iron 137

Constructional Steels

Standard Methods for Analysis of Iron and Steel 137
Isothermal Transformation Diagrams for Nickel-Alloy Steels 138
Properties of Sintered Nickel Steels 138
Boron-containing and other Low-Alloy Steels: U.S. Specifications 138
Nickel-Molybdenum Steel Tapered Roller Bearings 140

Heat- and Corrosion-Resisting Alloys

Specifications for Heat- and Corrosion-Resisting Alloys 140
Significance of Silicon in Nickel-containing High-Temperature Alloys 141
Hot-Twist Ductility Tests on Austenitic Nickel-Chromium Steels 141
Machining of Nimonic Alloys 142
Structure of Chromium Carbide in Austenitic Steels 142
Influence of Selenium Additions on the Properties of Stainless Steel 142
Cleaning and Finishing Stainless Steels 142
Resistance of Nickel-containing Materials to Copper Sulphate 142
Tantalum as Stabilizer in Austenitic Nickel-Chromium Steels 143
Nickel-containing Corrosion-Resisting Materials in By-Product Coke Plant 143
Corrosion-Resisting Materials in Marine Engineering 144
Corrosion-Resisting Materials in Corn-Refinery Plant 145
Tungsten Alloys produced by Infiltration 146

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HIGH-TEMPERATURE MATERIALS FOR GAS TURBINES

Iron and Steel Institute Symposium

'Symposium on High-Temperature Steels and Alloys for Gas Turbines.' Advance Copies of papers presented and discussed at meetings held in London, Feb., 1951; 303 pp.

The final forms of these papers, with discussion, will be published by the Iron and Steel Institute later in 1951, as Special Report No. 43; price £3 3s. 0d. To those who registered for attendance at the meetings the issue of the volume will be covered by the £2 2s. 0d. fee paid on registration.

The papers were presented in eight sections, see below. In almost all cases the information is of a comprehensive character within the scope of the individual subjects handled, and the volume as a whole represents a unique collection of data on composition, properties and uses of high-temperature materials developed and used for British gas-turbine components. Although the emphasis is primarily on materials of construction, the papers necessarily incorporate much useful information on design of the respective units in which the materials are used, and on the conditions in which they are required to operate. A commentary on the Symposium, by N. P. ALLEN, appears in *Nature*, May 26, 1951, pp. 836-8.

I. Introduction

N. P. ALLEN: 'A Survey of the Development of Creep-Resisting Alloys,' pp. 1-10.

The history of development is traced from the 1914-1918 war period, when the need for improved high-temperature materials first became urgently apparent. Research in England and America during the years 1918-1930 is briefly surveyed, with a table showing the composition of heat-resisting steels and alloys available in 1924.

Basic investigations in various countries, from 1930 to 1939, are reviewed, as a background to more detailed consideration of developments in the high-temperature field from 1939 onwards, when the main interest was the production of materials capable of operating under conditions involved in gas-turbine service. British, American and German activities are considered, in the light of the conditions obtaining in the respective countries, which to some extent governed lines of research and development.

In Great Britain the existence of limited resources dictated concentration of effort on a few types of material, which were selected at an early date, studied in detail, and gradually improved. Tables show compositions typical of the austenitic and ferritic steels developed at various stages during the war years, and of the nickel-chromium-base alloys which proved so important a contribution to progress in gas-turbine blading and other components.

Parallel development in U.S.A. took the form of investigation, on a less detailed basis, of a much wider range of compositions. Co-operative research, pursued under Government auspices at a large number of centres, eventually comprised an almost complete survey of the face-centred solid-solution alloys based on iron, nickel, chromium and cobalt, with various additions of molybdenum, tungsten, niobium and titanium. A large number of proprietary alloys of complex compositions was also examined, including new alloy series based on chromium, tungsten, titanium and cobalt. The reviewer gives some notes on the outstanding American alloys which were used in active service, e.g., nickel-molybdenum-iron types used for blading, and cobalt-base alloys employed for precision-cast blades, which were one of the noteworthy features of U.S. gas-turbine development.

German research in the high-temperature field was controlled to a marked degree by the shortage of raw materials, e.g., nickel, and a considerable amount of work was done on modification of design and on air cooling, to permit the use of materials involving less expenditure of strategic metals. Compositions typical of German austenitic and ferritic alloys are tabulated, and properties characteristic of the materials in use in Germany at the end of the war are graphically illustrated.

II. User Aspects

A. T. BOWDEN and W. HRYNISZAK: 'Materials and Performance,' pp. 11-17.

The paper is based on experience in operation of the Parsons experimental gas turbine, and on a general consideration of the use of relatively costly 'special' materials in gas-turbine components, and the criteria by which they are to be assessed. The need for simplification of design in blading, and for provision of material which can be used in the as-rolled or as-forged condition, are urged as primary requirements governing the prospects of large-scale development of industrial gas turbines. With regard to test requirements, it is suggested that the designer's and builder's essential demands are that the materials provided for gas-turbine manufacture shall have an adequate margin of safety against failure due to changes in the structure of the metal under working conditions, and that at any given time when fracture has not occurred the material shall still be ductile. It is therefore required that tests to which batches of material are subjected shall be truly representative, and of such a type as to give assurance to the user that the general

quality of the bulk supply of material or the component shall be equal to, or better than, the batch test results indicate.

Brief reference is made to the problem of corrosion and fouling by the products of combustion; this aspect of the subject is more fully discussed in other papers in the Symposium: *vide infra*. Experience with the Parsons turbine indicates that below about 650°C. blade corrosion (due mainly to vanadium, acting alone or in combination with sodium sulphate) is not severe.

Notes are added on materials for (1) compressors, for which aluminium bronze, mild steel and stainless iron have proved suitable, (2) combustion chambers, for which 18-8 chromium-nickel steels or heat-resisting alloys may be used, and (3) heat exchangers, for which no ideal material has yet been found to meet the exacting requirement of heat- and corrosion-resistance, coupled with moderate initial cost. In order to set in correct perspective the effect of temperature, and, therefore, of heat-resisting materials, on performance, the authors present, in the second part of the paper, a general picture of the place of temperature in relation to the limitations imposed on performance by other factors. Consideration is also given to methods of artificial cooling, which make possible the employment of constructional materials of lower heat-resisting capacity.

J. BUCHER: 'Gas-Turbine Performance and Materials,' pp. 17-23.

This paper deals primarliy with the need of the gas-turbine designer for further information on the materials of construction with which he is called upon to work. It is pointed out that for industrial and marine gas-turbine plants, reliability is the main feature; all components for such units should be designed for a life of at least 100,000 hours, except those required for purely peak-load purposes. In the open-cycle gas turbine the most difficult problem for the metallurgist is the material for the blading, while in the closed-cycle design the air-heater tubes present the greatest problem. Conditions obtaining in the two cases are briefly discussed, in relation to the properties required in the materials from which they are made.

For the designer of industrial gas turbines, fuller and more accurate information is required on four major points: (1) *creep-resistance*, in which connexion data from long-term tests at relatively low stresses would be particularly pertinent, especially for steels suitable for drawing into tubes for air-heaters, (2) *weldability* of high-temperature materials, (3) *influence of cold-working* on creep-resistance and other properties, and treatments which may be used to restore mechanical properties after cold working, (4) *resistance of high-temperature alloys to corrosion by products of combustion,* in which connexion resistance to vanadium-pentoxide attack is of major importance. The author reports comparative tests on various blading alloys, and briefly outlines alternative methods of overcoming the problem of corrosion of this type.

The final section of the paper is concerned with the desirability of developing, for use in the range 550°-600°C., a comparatively cheap steel having properties on a level between those of the best ferritic alloys and those of the cheaper grades of austenitic steel.

S. L. BRAGG: 'Influence of Operating Temperature on the Design and Performance of Gas Turbines,' pp. 23-9.

Primary variables in the simple gas-turbine cycle are the maximum (turbine-inlet) gas temperature, and the compressor-delivery pressure, the component efficiencies being secondary variables. Results of interest to the user are the specific output, which determines the size of the plant, and the overall efficiency, which affects running costs. Further variables are introduced by the addition, to the cycle, of other components such as heat-exchangers, intercoolers, and re-heat chambers.

The relative effects of all these variables are discussed in the first part of this paper, and it is shown that increasing the maximum operating temperature is the simplest method of obtaining considerable increases in both output and efficiency.

The second part of the paper deals with individual components of the turbine (compressor, discs, rotor blades, stator blades, combustion chambers): the limitation of design imposed by the physical properties of materials of construction is indicated. Arguments for and against cooling are briefly summarized, showing that in the interests of efficiency there will always be an incentive to use materials which, unaided, can withstand the high working temperatures involved.

The author suggests that, in developing improved materials for turbine blading, the emphasis should be on obtaining the same strength as has already been produced, at higher temperatures, while in turbine discs the requirement will be for higher strength at the comparatively low hub temperature, without sacrifice of resistance to oxidation at the hotter rim.

R. W. BAILEY: 'Stresses in Gas-Turbine Discs and Rotors,' pp. 30-5.

The nature of the operating stresses, and their distribution, are discussed in relation to 'thin' and 'thick' discs, and the behaviour of typical ferritic and austenitic steels under bursting tests (designed to simulate such stresses) is reported.

The results obtained on austenitic-steel discs indicate the important rôle of plastic strain in improving the resistance of the material at the central region of a disc or rotor, and thereby raising its bursting speed. Higher bursting speeds and higher bursting stresses are to be expected from ferritic steel discs than from corresponding austenitic steel discs of similar tensile strength.

The peculiar importance of the quality of disc centres is emphasized, and it is urged that special measures must be adopted to guarantee adequate properties in this respect. Means for evaluating disc-centre quality are discussed. Tests reported in this paper suggest that 'warm' work, suitably applied, may have a definite effect in raising the tensile strength

of discs at the inner region, without impairing ductility, and may also aid in increasing the bursting speed of rotors made up of discs. Further tests in this connexion are required to establish the general applicability of this conclusion. The final section of the paper deals with the effect of thermal stresses constantly repeated over prolonged periods of operation.

III. Supplier Aspects

L. B. PFEIL, N. P. ALLEN and C. G. CONWAY: 'Nickel-Chromium-Titanium Alloys of the Nimonic 80 Type,' pp. 37-45.

A review is made of the information on nickel-chromium-base alloys which, in 1939, provided a background for the development of high-temperature alloys for gas turbines. Survey of the literature, supported by unpublished data available in the laboratories of The Mond Nickel Company, indicated the potential usefulness of nickel-chromium alloys modified by small additions of other elements, and subjected to heat-treatments designed to produce precipitation hardening. Preliminary experiments showed the nickel-chromium-titanium group to be the most promising: this paper describes the development of alloys based on that series.

An account is given of methods used to determine the solid solubility of selected addition agents, the response of alloys of various compositions to heat-treatment, their forgeability, and their high-temperature properties, with special reference to creep-resistance.

The work described resulted in the development of Nimonic 80, of which the following is a typical composition: chromium 18-21, titanium 2-2½, aluminium about 0·5, per cent., balance nickel. The alloy is the subject of patents, and is covered by specification D.T.D. 725. The selected heat-treatment was 8 hours at 1080°C., followed by air cooling, and subsequent ageing for 16 hours at 700°C. The initial criterion of creep resistance was that the alloy should withstand a stress of 24 tons per sq. in. at 650°C. for not less than 100 hours, with a secondary rate of creep not exceeding 0·006 per cent. per hour. (The current specification for Nimonic 80 also lays down creep properties at 700° and 750°C.). Nimonic 80 was first produced on a commercial scale in 1941, and quickly became the standard blading alloy for British gas turbines.

The composition and structure of Nimonic 80 and of a modified alloy Nimonic 80A (D.T.D. specification 736) are discussed in relation to their high-temperature mechanical properties and creep-resistance, and the scale-resisting characteristics of the alloys are reviewed. Consideration is also given to evaluation of the properties of the Nimonic alloys under various conditions of temperature, stress and time, as affecting the use of such materials in conditions other than those for which they were originally developed.

D. A. OLIVER and G. T. HARRIS: 'Some Proven Gas-Turbine Steels and Related Developments,' pp. 46-59.

This paper deals with austenitic and ferritic heat-resisting steels developed by Messrs. William Jessop and Sons, Ltd., giving particular attention to two representative materials in each group: G.18B and R.20; H.40 and H.46.

G.18B was the first high-temperature steel in which appreciable additions of niobium and cobalt were made, in association with nickel, chromium, tungsten and molybdenum: it was also distinguished by utilization of large quantities of complex carbides. The composition of the steel is given as carbon 0·4, manganese 0·8, silicon 1·0, nickel 13·0, chromium 13·0, tungsten 2·5, molybdenum 2·0, niobium 3·0, cobalt 10·0, per cent., balance iron.

Steel of this type shows a good combination of resistance to scaling, creep resistance, fatigue strength (at normal and at elevated temperatures), freedom from embrittlement, and weldability. Extensive tabular and other data, on this material and on the other steels described, are given in the text and in an appendix, and attention is directed to the paper by Harris and Bailey (see next abstract), describing the process of 'warm working' used to develop optimum properties in G.18B. This steel was largely used in gas-turbine discs during the war period, and later was also employed for large solid rotors in land turbines. Long-time creep tests on G.18B, as produced for this application, are recorded, together with tests on another rotor steel, R.20 (a 14-19 per cent. nickel-chromium steel type, of lower carbon content and containing about 1·7 per cent. of niobium). Work in connexion with the welding of these steels is reported by Bailey (see abstract on p. 125).

The second part of the paper reviews properties typical of some ferritic steels which have proved suitable for high-temperature service, including H.31 (a 1 per cent. chromium-molybdenum type), H.40 (3 per cent. chromium-molybdenum-vanadium steel) developed to give improved creep-resistance, and H.46 (a modified type of 11 per cent. chromium steels containing small percentages of molybdenum, vanadium and niobium).

The authors also make reference to steels for cast turbine casings and for relaxation-resisting bolts. The respective applications of G.21 (13 - 13 nickel - chromium steel containing tungsten and niobium), G.18B, H.40, and H.46 are considered.

Some techniques adopted for processing and inspection of turbine blading are briefly described and illustrated, and notes are added on types of blading potentially alternative to the solid high-duty machined blades which, up till now, have been favoured in Britain.

A short, but informative, section of the paper is concerned with the influence of gas atmosphere on the oxidation- and scaling-resistance of high-temperature steels. The severely injurious effect of vanadium pentoxide is demonstrated, and attention is drawn to the relatively good resistance of the high-cobalt steel G.32.

The paper closes with a condensed review of (1) the main factors affecting progress (urging the provision of additional precision creep, stress-rupture and high-temperature fatigue data) and (2) trends in development (use of increasing temperatures, methods which may be adopted for cooling, and the economic and supply factors governing use of alloy materials).

G. T. HARRIS and W. H. BAILEY: 'Effect of 'Warm-Working' on an Austenitic Steel (G.18B),' pp. 60-7.

In connexion with the use of G.18B steel for turbine discs it was found that although the creep strength of the steel was sufficiently high to preclude failure resulting from inadequate creep strength at the rim, when operating conditions became more severe the problem of disc growth was encountered. This growth took place mainly at the centre of the disc, which was comparatively cool, but was often stressed to a value beyond that of the proof stress of the material. Experiments showed that an improvement of the order of 90 per cent. in the proof-stress value could be obtained by drastic cold-working, but that such treatment resulted in improvement in creep strength only under certain testing conditions, and that it was usually accompanied by lowered rupture strength. Further work was therefore initiated, to ascertain the influence of mechanical working at a temperature approaching, or even exceeding, the operating temperature. Tests were carried out, at various temperatures in the range 600°-900°C. using the following methods of working: (1) pressing between flat tools, (2) working in tension, and (3) stamping in closed dies. The mode of operation of the three methods, and the results obtained by them, are recorded in this paper.

The data obtained indicated the possibility of substantial improvement in both the room-temperature tensile strength and the high-temperature creep properties of the G.18B steel by warm-working. On the basis of results producible, equipment available, and economic considerations involved in large-scale production, the method of drop-stamping was chosen as most suitable for routine use. Current practice is as follows: Following solution treatment at 1300°C., and any subsequent machining required, the turbine discs are heated at 700°C. in a gas-fired furnace, and after an adequate soaking period are transferred to a 10-ton drop stamp, in which they are given a small number of blows, controlled closely according to requirements. Properties regularly obtained in material so treated are shown in the paper.

Although the major part of the paper relates to the improvement in room-temperature tensile properties produced by warm working, the persistence of the beneficial effect on creep properties has also been studied. Long-term tests show that the effect of the treatment is still in evidence after periods of up to 10,000 hours. General problems involved in warm-working, and the applicability of the method to other materials used for different purposes, are briefly discussed.

G. T. HARRIS and H. C. CHILD: 'Development of a High-Temperature Alloy for Gas-Turbine Rotor Blades,' pp. 67-80.

The authors describe results of a systematic investigation of composition and heat-treatment variables, on the creep and rupture strength of austenitic alloys based on the nickel-cobalt-iron-chromium series. The research resulted in development of the steel known as Jessop G.32, details of which are given.

The work was carried out in three sections:—

(I) *Preliminary Work with Arbitrary Selection of Base and Strengthening Elements*

(*a*) Effect of various carbide-formers on a 20 per cent. Ni, 20 per cent. Co, 20 per cent. Cr base, containing also 0·5 per cent. C.

(*b*) Effect of carbon content in alloys containing 20 per cent. Ni, 20 per cent. Co, 20 per cent. Cr, with additions of 3 per cent. V, 3 per cent. Mo and 3 per cent. Nb.

(*c*) Effect of base composition on 3 per cent. W, 3 per cent. Mo, 3 per cent. Nb alloys containing 0·5 per cent. C.

(II) *Principal Systematic Investigation*, using some of the results obtained under (1)

(III) *Miscellaneous Investigations*

(*a*) Effect of heat-treatment.

(*b*) Constitution of some representative alloys.

A detailed report of the work in each of the above sections is given, with succinct summaries of the main results, essential features of which are given below :

(I) When carbide formers are progressively added to an alloy of given carbon content the high-temperature strength properties pass through a maximum value, and, similarly, when the carbon content of an alloy with given carbide formers is progressively increased a maximum also occurs. There exists a 'complexity effect' whereby the high-temperature strength of an alloy can be improved by increasing the number of carbide-formers present, and a major finding is the importance of ensuring optimum balance between the carbide formers and the complexity effect. A tentative explanation of the inter-relationship of these two factors is suggested.

(II) The optimum composition developed as a result of examination of the large number of alloys studied in the main investigation was as follows: carbon 0·3, manganese 0·8, silicon 0·3, nickel 15, iron 15, chromium 19, vanadium 2·8, molybdenum 2·0, niobium 1·2, cobalt 43, per cent. In a modified form of the alloy the nickel content is 12, cobalt 45, iron 16, per cent., approx. Creep, stress-rupture and fatigue properties of G.32 at 700°-850°C. are tabulated.

(III*a*) In connexion with heat-treatment, consideration was given to the influence of (1) temperature and time of solution treatment and subsequent rate of cooling; (2) ageing after solution treatment; and (3) warm working after solution treatment. The treatment which proved to develop the best combination of properties comprises heating for 5-15 minutes at the temperature of the solidus, or just below it, followed by cooling at a rate faster than air-cooling. Full ageing treatment is then given at 700°-800°C.

(III*b*) In the type of alloys studied, the carbide-forming power of the elements chromium, molybdenum, tungsten and niobium increases in that order. The nature of the phases occurring, and the constitution of the precipitate responsible for age-hardening in some of the alloys are discussed.

H. W. KIRKBY and C. SYKES: 'Properties of Materials Intended for Gas Turbines,' pp. 81-94.

The main object of this paper is to indicate the progress made in the large-scale manufacture of typical

gas-turbine materials, by giving a number of examples of forged components made in various steels, and an account of their properties. Ferritic and austenitic grades are included, as exemplified by some steels produced by Messrs. Firth-Brown, Ltd.

Much detailed information is given on the composition, properties, testing and applications (in gas-turbine components) of the following types of steel:

1. *Ferritic Types*

Molybdenum-bearing grades, including carbon-molybdenum, chromium-molybdenum and nickel-chromium-molybdenum steels.

Molybdenum-vanadium-bearing grades, including plain molybdenum-vanadium and chromium-molybdenum-vanadium (with or without tungsten) steels.

Much information is given on tests from actual service components made from these steels, as well as on test specimens of the steels as such. Reference is also made to R.ex 448, an improved type of creep-resisting steel containing 10-12 per cent. of chromium.

2. *Austenitic Types*

In this section a considerable amount of information is given on the properties of F.C.B. (T) steel, containing carbon 0·12, chromium 17·5, nickel 12·0, and niobium 1·0, per cent., developed to meet the requirement for a steel combining good creep properties with the ability to be hot-worked in fairly large sizes.

A second austenitic steel discussed is 326, for which a typical composition is carbon 0·25, manganese 3·0, chromium 17·0, nickel 17·0, molybdenum 2·5, niobium 1·8, cobalt 7·0, per cent. The creep properties of this steel are superior to those of F.C.B. (T), and it is claimed to be suitable for use at temperatures up to 720°C. It has good forging properties. Details of heat-treatment are given, and typical properties are tabulated.

The third austenitic steel to which special reference is made is 337, containing carbon 0·2, chromium 17·0, nickel 17·0, molybdenum 3·0, copper 3·0, titanium 0·8, cobalt 7·0, per cent. It is a development of the early R.ex 78, and its creep-resisting properties are superior to those of both F.C.B. (T) and 326. Due to its high hot-strength, 337 is not readily produced in the form of large and complicated forgings. Its useful range of operation goes up to 750°C.

Production and inspection procedure, for both ferritic and austenitic steels, is briefly discussed and some consideration is given to probable future lines of development in materials for gas-turbine components. Cost, and the need for conservation of strategically important alloying elements, will play a large part in determining the trend of progress, and in the latter connexion reference is made to a modified 337-type steel, which contains neither cobalt nor niobium. For this steel, designated R.ex 467, no specific details of composition are given, but properties at temperatures up to 750°C. are recorded.

H. W. KIRKBY and C. SYKES: 'Study of the Properties of a Chromium - Nickel - Niobium Austenitic Steel,' pp. 95-106.

The paper deals mainly with a study of an austenitic 18-10 chromium-nickel steel stabilized with niobium, and with investigation of steels containing higher percentages of nickel, e.g., F.C.B. (T). The majority of the data refer to bar material, of the following composition: carbon 0·11, silicon 0·50, manganese 0·41, sulphur 0·011, phosphorus 0·014, nickel 9·5, chromium 17·84, niobium 1·22, per cent. Some comparison is made with the properties of forgings of steel of the same type.

The data presented comprise determination of creep properties for testing times up to 20,000 hours, at temperatures over the range 550°-700°C., also short-time tensile-test results for the same temperatures.

The effect of long exposures at elevated temperature was also investigated, using, in most cases, a temperature of 650°C. The degree of structural change resulting from such exposure was determined by the alteration produced in room-temperature mechanical properties, and by use of photomicrographic and X-ray techniques. The structure of specimens which had been exposed to creep test was also examined, and the susceptibility of the steel to sigma formation under exposure to high temperatures was determined.

The information given indicates the suitability of the 18-10 type of steel for applications such as rotor forgings, blades and tubes, working at temperatures up to 650°C. Mechanical and metallographic tests confirm that if the nickel content is in the range 9-13 per cent. little or no austenite breakdown occurs on exposure at such temperatures. The small amount of sigma phase formed, even after long periods of exposure at 550°-850°C., is considered to be insufficient to cause any significant loss in ductility. It is noted in this connexion that the amount of sigma phase present was not appreciably influenced by the amount of nickel, within the range studied.

Certain unusual features in the shape of the creep curves are discussed, and consideration is also given to the influence of heat-treatment on creep-resistance at 650° and 700°C., coupled with the effect of grain size.

E. W. COLBECK and J. R. RAIT: 'Creep-Resisting Ferritic Steels,' pp. 107-24.

An introductory survey of the factors contributing to the increased demand for ferritic steels of improved quality includes a summary of the relative advantages and limitations of ferritic and austenitic steels for high-temperature service.

Following an account of the properties of low-alloy chromium-molybdenum steels of the Hecla 153 and related types, attention is directed to an outstanding material in the ferritic group, the 3 per cent. chromium-molybdenum-tungsten-vanadium steel (H.G.T. 3) developed by Messrs. Hadfield. This type of steel has been studied in close detail, in order to determine the individual effects of composition, constitution and heat-treatment, on creep and other properties. Much detailed information is given in this paper.

A second section of the paper deals with investigations on a series of steels of the chromium-molybdenum-tungsten-vanadium type, in which chromium was systematically varied from 0 to 12 per cent.

Results from both series emphasize that in order to

obtain good creep properties it is essential to obtain a minimum amount of stable cubic carbide of the NaCl type of structure, and that what is present should be in as finely dispersed a state as possible. To obtain the carbides in this condition it is important to avoid formation of delta ferrite, and also to obviate changes in composition of the ferrite solid solution which would adversely affect the strength of the ferrite.

The studies have provided fundamental data which will make possible, in the near future, the development of three other creep-resisting steels containing molybdenum, vanadium and tungsten, one of them chromium-free, the other two containing, respectively 1 and 12 per cent. of chromium.

H. H. BURTON, J. E. RUSSELL and D. V. WALKER: 'Ferritic Steels for Gas Turbines,' pp. 125-34.

This paper also describes work on the chromium-molybdenum-tungsten-vanadium types of steel: it is based on developments at the English Steel Corporation, Ltd. Some data on two molybdenum-vanadium steels are also presented.

The majority of the test data relate to Hykro V.80, which has been used for discs in gas-turbine engines; properties of material from forged discs, as well as from bars, are recorded. Comparison is also made, from the point of view of gas-turbine requirements, with the properties of molybdenum-vanadium steel and of a chromium-molybdenum-vanadium steel of low alloy content.

The data reported show that the Hykro steels are able easily to meet normal creep-resistance requirements at 600°C., and that the low-alloy chromium-molybdenum-vanadium steel has definite potentialities as a disc material, particularly in view of its low alloy content (and consequent lower price), and the lower hardening temperature required. It is believed also to have interest in the steam-turbine field, but in this connexion its response to heat-treatment in large mass has to be further explored.

W. E. BARDGETT and G. R. BOLSOVER: 'Special Steels for Gas Turbines,' pp. 135-48.

The paper is mainly concerned with a complex alloy intended for high-temperature service, tested as a 2-ton forging, step-pressed to give various degrees of reduction. This material, referred to as 'Multi-Alloy', has been superseded, but the data are presented as being of interest in connexion with the general question of influence of individual elements, and the effect of the amount and direction of forging.

Preliminary tests at 650°C. indicated high resistance to creep in a steel of the following composition: carbon 0·25, manganese 1·63, silicon 1·03, nickel 46·52, chromium 20·5, molybdenum 2·73, cobalt 3·33, niobium 2·92, tungsten 3·52, titanium 1·20, per cent. Tests were first made to determine the effect of omission, one by one, of the elements molybdenum, cobalt, niobium, tungsten, titanium, on creep behaviour at 650° and 800°C. The influence of addition of 0·73 per cent. of vanadium was also investigated. The effect of the respective elements was found to vary according to the temperature of test, but the full Multi-Alloy composition proved to be optimum over the widest range of temperature.

A 2-ton ingot of this material was step-pressed, to give forging reductions of 25, 50 and 75 per cent., and tests were made on samples so produced, in comparison with unpressed material. Determinations of creep and of general mechanical properties indicated little effect of direction of test (transverse or longitudinal) or amount of hot work which the material had undergone.

A second section of the paper describes a 25-15 chromium-nickel steel known as Red Fox 31*; typical analyses of two casts are given.

Data on mechanical properties and creep given in the paper show that this steel, which has already given excellent service in many high-temperature applications, e.g., superheater supports, at temperatures in the region of 1100°C., has only poor load-carrying capacity, even at 800°C., in comparison with steels of higher alloy content. The high resistance to scaling and the relatively good weldability of the steel are, however, points of importance in certain applications, as in combustion chambers.

A steel of somewhat higher total-alloy content (chromium 20, nickel 30, titanium 1-2, per cent.), developed under the name of Red Fox 33*, has proved to have especially good creep-resistance at 650°C. This paper gives an account of investigations to determine the influence of titanium content and heat-treatment, and also records embrittlement tests on unstressed and on stressed specimens under prolonged exposure at 650°C.

None of the unstressed specimens (titanium 0·73-1·60 per cent.) showed a serious degree of embrittlement; both original and final impact figures tended to fall with increase in titanium. Stressed specimens were, in general, slightly more embrittled than the corresponding unstressed samples.

In this steel the phenomenon of negative creep was observed; examples of its occurrence, in various specimens, and under varying conditions of test, are recorded. Dimensional stability of the steel has been examined as one of the factors constituting negative creep; preliminary results show marked dependence of stability on the initial condition of the material. Further tests are being made to determine quantitatively the effect, on dimensional stability, of changes in composition and heat-treatment, and to ascertain whether directional properties are involved.

IV. Performance Aspects. Scaling and Fatigue at Elevated Temperatures

A. PREECE: 'Scaling of Gas-Turbine Alloys,' pp. 149-52.

Experience in production of alloys for service at high temperatures has shown that certain alloying elements, notably chromium, serve a dual purpose, conferring oxidation-resistance as well as mechanical strength. Because most of the high-temperature alloys used up till now have contained a considerable amount of chromium, little trouble has been experienced from the point of view of oxidation. The use of fuel oils containing vanadium and sodium has, however, introduced serious problems of oxidation, which threaten to delay progress in the application of the gas turbine in a wide field.

**Messrs. Samuel Fox and Co., Ltd.*

This paper discusses the fundamental laws of oxidation, and the conditions governing the formation of protective films, with particular reference to conditions which may cause breakdown of such protection in contact with fuel oils. The nature of the attack imposed, the mechanism of the breakdown of the protective film, and the composition of the ashes resulting from burning of fuel oils are reviewed. The solution of the problem appears likely to be along the lines of addition of inhibiting substances to the oils, rather than the development of alloys resistant to attack of ash from unmodified oils. In the latter connexion, however, it has been noted that the composition of the alloy is not without significance; iron and high molybdenum contents have a deleterious influence; high nickel contents appear to be beneficial.

C. SYKES and H. T. SHIRLEY: 'Scaling of Heat-Resisting Steels. Influence of Combustible Sulphur and Oil-Fuel Ash Constituents,' pp.153-69.

The paper opens with a description of the oxidation and scaling test which for many years past has been standard in the Brown-Firth Research Laboratories, for determination of the characteristics of heat-resisting materials. Modifications in method made to provide for testing resistance of materials to sulphur-containing gases, to ash residues, and to the products of combustion of oil fuels, are also described. In these cases temperatures of test have in many cases been adjusted in relation to conditions involved in gas-turbine service.

An account is then given of an extensive series of tests made, with the apparatus described, on heat-resisting steels of representative types, covering (1) steels having specially high creep-resistance (337 and 326 types, varying in composition in such a way as to illustrate the influence of individual alloy elements, especially chromium; (2) typical heat-resisting steels which are widely used in industry, e.g., F.C.B.(T.), F. S. T., F. D. P.; 25 per cent. chromium steel, Immaculate 5 and H.R. Crown Max.); (3) R.ex 400 (an alloy of specially high creep-resisting properties, containing nickel 76·0, chromium 19·16, titanium 2·14, aluminium 0·64, per cent.). Full compositions of all the test materials are given.

A detailed report is made of tests to determine the effect of air/gas ratio; effect of combustible sulphur at varying air/fuel ratios; influence of oil-ash constituents, including the effect of sodium sulphate and of vanadium pentoxide; effect of molybdenum oxide. Most of the tests were made at 750°C., but in a few cases the range was wider, 700°-800°C. Tests are also included on the heat-resisting steel group in the range 850°-1100°C. Consideration was also given to the possibility of protection by coating with chromium or aluminium; in this connexion tests were made on both of these metals, and on a chromium-plated cylinder, in contact with pure vanadium pentoxide and with an ash mixture.

The results are summarized in particularly clear and accessible form, for which the original must be consulted. They indicate that sodium sulphate has not a severely corrosive effect, but that the presence of only 0·3 per cent. of sodium chloride in the sodium sulphate results in serious acceleration of attack in air at elevated temperature. Combination of sulphur and sodium sulphate has also a highly deleterious effect. Contact with vanadium pentoxide, or a synthetic oil-ash mixture containing 26·5 per cent. vanadium pentoxide, produced severe attack at 750°C. on all the materials tested. Attack lessened at temperatures below 650°C., and at 550°C. was not observed after 20 hours' exposure. Results indicate that neither chromium nor aluminium can be expected to provide useful protection at 750°C.

Vanadium pentoxide exercized a catalytic effect on attack by sulphur. Contact with molybdenum oxide, either solid or as vapour, in static or flowing air, produced severe acceleration of attack (tests on 337, 326 and F.C.B. (T.)).

H. J. TAPSELL: 'Fatigue at High Temperatures,' pp. 169-74.

The paper is based on work at the National Physical Laboratory. The importance of fatigue-resistance at high temperatures is emphasized, in connexion with gas-turbine and other materials, and consideration is given to the general characteristics of the behaviour of metals in fatigue, together with discussion of modifications introduced by the presence of mean steady stresses which cause creep.

The effect of plastic strain, in modifying stress distribution under bending conditions, is described, and the importance of cyclic speed of stressing is demonstrated.

Experimental fatigue data are shown for the following materials, and are correlated with creep data: R.ex 78 (as produced in 1941); Nimonic 80 (1942-43 grade); G.18B (1943-44 deliveries); Nimonic 80 (1945 grade) G.32 and R.ex 337A, both made available in 1947. Method of correlating these data in working-stress diagrams is shown.

A section at the end of the paper makes brief reference to additional tests made at the N.P.L. to determine the effect, on fatigue strength, of (*a*) exhaust gases from a combustion chamber burning kerosene, (*b*) small fillet radii, and (*c*) welds. In all three sections the work was done on R.ex 78 and on Nimonic 80.

P. H. FRITH: 'Fatigue Tests at Elevated Temperatures,' pp. 175-81.

A report is made of tests on the following materials, at the temperatures shown in brackets: Nimonic 80, rolled bar (700° and 800°C.); improved Nimonic 80 rolled bar (20°, 500°, 700° and 800°C.); G.32 rolled bar (700°C.); re-melted and cast Nimonic 80-type bar (500°, 600°, 700° and 800°C.), and re-melted and cast G.18B-type bar (500°, 600°, 700° and 800°C.).

The tests were made on hollow test pieces, with reversed bending stresses, and with reversed bending stresses superimposed on a static tension or static bending stress. A few tests were made on turbine blades with reversed bending stresses.

For the room-temperature tests a Wöhler-type machine was used; the high-temperature tests were made on the N.P.L. combined-stress-fatigue testing machine, as modified by the Bristol Aeroplane

Company, in whose laboratories this work was carried out. A description of the high-temperature machine is given in an appendix to the paper.

H. E. GRESHAM and B. HALL: 'Hot Fatigue Testing,' pp. 181-5.

The paper describes an alternating-bend fatigue-testing machine developed in the laboratories of Messrs. Rolls-Royce, Ltd. Full details are given of design, materials of construction and operating technique, and the furnace associated with the installation is described, with diagram. A note is added on investigations made on a method for accurate recording of the temperature of the specimens while under test.

In demonstration of the information obtainable, curves show results of tests on a steel to D.T.D. 49B, from which an accurate endurance limit of 10 million reversals of stress, and an estimated limit for 100 million cycles, may be obtained.

A number of the investigations made with the apparatus described have been in connexion with engine problems in which fatigue-under-corrosion conditions were involved. The adaptability of the fatigue-test apparatus for this type of investigation is illustrated by reference to tests on—

(1) Nimonic 80 in contact with low and with high concentrations of sulphur dioxide; and

(2) Brightray and steel to D.T.D. 49B, in contact with lead salts, demonstrating the advantage of using Brightray as a coating over the seat and tulip of the austenitic-steel base material.

A photograph is also shown of the fatigue-testing machine modified for working under salt-spray conditions, and of an electronically operated machine designed to vibrate the specimen at much higher frequencies than are attained with more conventional equipment. Using this machine (at present only in the development stage), tentative data have been obtained on the effect of a cold-worked surface on the fatigue strength of turbine-blade materials. Cold-working has been shown to cause no appreciable reduction in the hot-fatigue strength of Nimonic 80A when the mean stress is zero, but to reduce fatigue strength when the material is subjected to creep stresses before fatigue testing.

G. T. HARRIS and M. T. WATKINS: 'Variation of Elastic Moduli with Temperature for Various Steels and Pure Metals,' pp. 185-8.

Determination of the stresses in gas-turbine parts, as in all structures for use at elevated temperatures, requires a knowledge of the variation of Young's modulus and the modulus of rigidity, with temperature. This question has recently received much attention, and a considerable literature has accumulated on technique of determination. The major papers are mentioned as an introduction to this report.

The present authors used both static and dynamic methods for their determinations; the essential features of both procedures are described.

Data are presented, over the range 25° to 700°C., for the materials shown below; in a few cases values for 800°C. are also shown:—

Armco iron, aluminium, nickel;

Ferritic steels (Jessop E.1, G.0, H.27, H.40, H.46);

Austenitic steels (Jessop R.16, R.20, R.22, G.2A, G.21, G.18B, G.32).

Full details of composition of the materials are given. For G.18B and R.20 steels determinations were made of variation, with temperature, of the modulus of rigidity and Poisson's ratio.

V. Special Casting Techniques

A. E. THORNTON and J. I. MORLEY: 'Centrispun High-Alloy-Steel Aero-Engine Components,' pp. 189-205.

Part 1: 'The Centrispinning Process,' by A. E. THORNTON, pp. 189-94.

'Centrispinning consists essentially in the introduction of liquid metal into a rapidly rotating mould in such a way that the metal is directed, under centrifugal force, to take up the shape of the mould into which it is being poured.' Extensive use has been made, in the aircraft industry, of centrispun die castings of high-alloy heat-resisting steels.

Part 1 of this paper outlines the essential features of the centrispinning process and discusses its advantages and limitations from a metallurgical point of view. Results of mechanical tests on sections cut from representative centrispun castings are given, as produced, for example, from H.R. Crown Max and F.C.B. nickel-chromium heat-resisting steels. These demonstrate the high mechanical properties obtainable in centrispun products, and illustrate the influence of the type of mould (permanent metal, or refractory) on the properties of the castings.

Factors of major importance in casting technique are discussed, and inspection methods used on centri-die-cast products are described.

Part II: 'Physical and Mechanical Properties of Centrispun Die Castings,' by J. I. MORLEY, pp. 195-205.

The three steels which have been produced most extensively in the form of centri-die castings for turbo-jet and gas-turbine applications are F.D.P. (18-8 Ti-stabilized); F.C.B. (T.) (18-12 containing niobium), and H.R. Crown Max (23-12 containing about 2·5 per cent. tungsten). The data recorded in this paper relate to castings of these materials: they were obtained from rings spun in metal moulds, in a size of casting typical of many jet-engine components.

Details are given of macrostructure, Young's modulus, scaling-resistance (as determined by the Hatfield scaling test (see p.122, paper by SYKES and SHIRLEY), microstructure, and behaviour in creep and stress-rupture tests. (In the long-time high-temperature tests the data relate to H.R. Crown Max only.)

From the large amount of experimental data accumulated, the following general conclusions are drawn:

For all three materials, the structure of the castings air-cooled from 1050°C. is substantially free from sigma phase, with consequently adequate ductility at room temperature.

Over 3,000 tons of machined components in H.R. Crown Max have been supplied to the aero-engine industry, and from the service experience with these and other castings it may be concluded that each of the steels has its own advantages and limitations. H.R. Crown Max has the highest scaling-resistance,

and should be used at operating temperatures of 850°C. or above. It is also the most suitable for intricate castings. F.C.B. (T.) has satisfactory scaling resistance up to 800°C., and its creep properties are the highest in this group, but its casting qualities are not so good as those of the other two materials, and it has limited ductility in large castings. F.D.P. shows scaling-resistance similar to that of F.C.B. (T.) and has good ductility and adequate stability.

An appendix to the paper gives the melting range for H.R. Crown Max. and contains a detailed study of the sensitivity of this steel to changes in composition. Centri-die castings of this 25-12 chromium-nickel steel, if highly duplex in structure, are susceptible to marked sigma embrittlement, and show inferior creep-resistance at 700° and 800°C. By modification of composition (lower carbon and higher nickel) excellent creep properties can be obtained. This improvement is secured at the expense of lowered room-temperature ductility in large castings.

J. TAYLOR and D. H. ARMITAGE: 'Centrifugal Steel Castings for Gas Turbines,' pp. 205-8: see also *Foundry Trade Jnl.*, 1951, vol. 90, pp. 263-5 (Abridgement).

The authors describe methods in use at Messrs. David Brown Foundries, Ltd., Penistone. Foundry equipment and production technique are discussed, and the fields of application of the horizontal- and the vertical-axis methods are reviewed.

The stringent methods of inspection adopted at this foundry are also outlined.

The castings produced are mainly of two types:

(1) castings for operation at normal atmospheric temperature, but produced in high-tensile steel to secure weight reduction. These are chiefly of low-alloy types, containing up to about 1½ per cent. chromium, 2 per cent. nickel, ½ per cent. molybdenum, with 0·3 per cent. carbon;

(2) castings for operation at elevated temperatures, requiring strength and resistance to scaling. In some cases imperviousness to gases, and weldability, are also specification requirements. The three materials most usually employed for centrifugal castings of this type are 18-8 niobium, 25-12-3 chromium - nickel - tungsten, and an alloy containing nickel 80, chromium 15, per cent.

H. E. GRESHAM and A. DUNLOP: 'Investment-Casting of Nozzle Guide Vanes,' pp. 209-12.

The essential principles of the investment (or lost-wax) process are described, with particular reference to the three major respects in which the method differs from normal production of castings in sand moulds. Production technique is then outlined, step by step, as involved in application of the process to manufacture of nozzle guide vanes in heat-resisting nickel-chromium steels (by Messrs. Rolls-Royce, Ltd.). Particulars are given of production of the master die, wax-pattern production and assembly, pattern investment, heat-treatment of the mould, casting, and finishing operations. Scope of the process, in relation to gas-turbine components, is discussed, on the basis of experience in America (where the method has been more widely adopted than in this country) and England.

The degree of precision obtainable by investment casting is critically considered, and properties of investment castings are reviewed. A table shows creep and stress-rupture data, at temperatures of 800°-1050°C., for investment castings of H.R. Crown Max steel, G.18B steel, a cobalt-base alloy containing chromium and molybdenum (Vitallium type), a nickel-base alloy containing chromium 15, molybdenum 15, tungsten 3, per cent., and a nickel-base alloy containing chromium 20, cobalt 20, molybdenum 5, aluminium 5, per cent.

E. R. GADD: 'Precision-Casting of Turbine Blades,' pp. 212-16.

This paper also opens with a serial description of the steps involved in casting by the investment process, but the two papers are complementary, in that the individual experience of each of the authors supplements the generalities of the information given. The Bristol Aeroplane Company, on whose practice this paper is based, has dealt with Nimonic 80, H.R. Crown Max and steel to D.T.D. 49B.

The major application of precision casting in the British aero-engine industry is for turbine blades, the greater proportion being stator blades. At Bristol stator segments have been the main product, and the Company has built up considerable experience in this connexion; different types of stator segment and rotor blade produced are illustrated in the paper. With regard to production methods, emphasis is placed on the need for precise control at all stages, particularly in preparation of the wax model.

Casting defects likely to be met with when using this process are discussed, with indication of their probable causes, and some means for obviating them: shrinkage cavities, blow holes, cold shuts, and surface defects are individually considered.

In connexion with the properties of precision-cast turbine blading, attention is directed to the paper by Frith (*ibid.*, pp. 175-81) which includes data on Nimonic 80 blading so produced.

The importance of thermal-shock resistance in blading is being increasingly recognized, and the Bristol Aeroplane Company has devised a test by which this property of the material can be assessed. A description (with photograph) is given in the paper, and results of the thermal-shock test made by this method are detailed. These relate to R.ex 337, Nimonic 80, H.R. Crown Max, Nimonic 75 and G.18B.

VI. Welding and Machinability Aspects

H. E. LARDGE: 'Welding of Heat-Resistant Alloys in Sheet Form,' pp. 217-24: see also *Aircraft Production*, 1951, vol. 13, pp. 84-7, 121-3.

The author describes welding techniques developed for assembly of precision metal work in gas turbines, discussing the metallurgical and engineering problems involved. In order to exemplify some of the problems presented by this type of assembly, a brief description is given of the sheet-metal components of a typical gas turbine, and of the materials which are used for

the various parts:—mild steel, 18-8 of various types, Inconel, Nimonic 75 and H.R. Crown Max. The physical and mechanical properties of these materials which affect their welding characteristics are tabulated.

The main paper comprises a review of the various methods of welding adopted (in the works of Messrs. Joseph Lucas, Ltd.) for joining of some or all of the above materials. Sections of the paper describe technique used in fusion welding by the oxy-acetylene, carbon-arc, argon-arc and metallic-arc methods, and the procedures adopted for resistance welding (spot, stitch and seam). Some of the specialized methods and equipment found necessary for handling the gas-turbine materials are described and illustrated, and the paper includes a number of photographs showing types of component for which welded assembly was used, structures of welds produced by various methods, and sections of welded materials.

The author recommends that, in the interests of future progress, attention be given to development of automatic metallic-arc-welding equipment for handling the austenitic steels, the further development of brazing alloys, and the production of resistance-welding equipment suitable for gauges heavier than can be handled on existing types.

E. BISHOP and W. H. BAILEY: 'Weld-Metal Properties and Welding Characteristics of Two Austenitic Steels Used for Gas-Turbine Rotors,' pp. 225-32.

This paper deals specifically with the welding of G.18B and R.20 steels, as representative of materials used for gas-turbine rotors: it records methods developed as a result of joint research by the B.S.A. Group Research Centre and Messrs. William Jessop and Sons, Ltd. For the welding of G.18B special electrodes were developed, using core wire of the same composition as the parent steel (modified by slight reduction in carbon and increase in tungsten), with a coating of the usual silicate-bonded chalk-fluorspar type, having an alloy content calculated to replace losses occurring in the welding arc. With such electrodes, crack-free welds are consistently obtained.

The authors give much detailed information on design of the arc-welded joints, and on technique of welding, and report the room-temperature properties of all-weld-metal specimens and of butt joints welded in 1-inch thick plate. Mechanical properties of the welded joints, in the as-welded condition and after heat-treatment, were studied at room temperature, and creep properties were determined at temperatures at which the respective materials would be used in service.

G.18B steel was found to have excellent welding properties, and the creep-resistance of the welded joints was even slightly superior to that of the wrought parent material. With R.20 difficulties were at first experienced, due to formation of a brittle intergranular constituent in the weld metal, but development of a modified form of electrode eliminated this defect. The tentative specification for weld-metal composition deposited by electrodes for welding R.20 forgings is given as carbon 0·12-0·16, manganese 0·7-1·5, silicon 0·30 max., sulphur 0·030 max., phosphorus 0·030 max., nickel 13·0-15·0, chromium 18·0-20·0, per cent., niobium 8-10× carbon. The factor of primary importance is the silicon content: if this be kept below 0·30 per cent. the permissible niobium content may probably be raised, but with higher silicon cracks may occur even with low niobium/carbon ratios. It is suggested that special casts of R.20 for welding wire should be made to a specification of silicon 0·20 per cent. max. As in the case of G.18B, welded butt joints made in R.20, with electrodes of optimum composition, showed better properties than the parent material.

K. J. B. WOLFE and P. SPEAR: 'Machining Austenitic and Ferritic Gas-Turbine Steels,' pp. 233-42: see also *Aircraft Production*, 1951, vol. 13, pp. 80-3; 117-20.

Development in materials for gas-turbine construction has presented machine shops with three basic problems:

(1) Machining of materials with machining properties inferior to those of steels and alloys normally handled.
(2) Production of components with high degrees of finish and much closer tolerances than those previously specified.
(3) Inspection of these components.

This paper deals with the fundamental problems encountered in relation to tool material and design, cutting fluids, cutting speeds, feeds and depths of cut and other factors encountered in producing swarf from the high-alloy materials used for heat-resisting components. In introducing the paper, the authors give reference to several comprehensive surveys which have been published describing methods employed by representative workshops handling these materials.

A table is then given showing the approximate compositions of typical high-temperature alloys and steels, and a summary is made of the general machining characteristics of such materials, indicating the respects in which they call for equipment and procedure different from that used for mild steel and the easier-machining non-ferrous alloys. The following sections of the paper contain a clear and comprehensive discussion of the various aspects of the subject:—

(*a*) *selection of cutting-tool material*: fundamental requirements for the tools, typical compositions, hardness, and advantages and limitations of individual types of tool material, with notes on applications suitable for the respective types; notes on effect of surface condition on life of high-speed-steel tools, and the effectiveness of various specialized surface treatments;

(*b*) *selection of cutting fluid and application*: uses of four grades of cutting fluid, and modes of application, with diagrams of typical layouts;

(*c*) *design of machine tools and jigs and fixtures*: notes on requirements for strength, rigidity, avoidance of backlash, ample supply of cutting fluid, choice of speed ranges, etc., and design of jigs and fixtures;

(*d*) *machining conditions*: discussed by reference to four classes of material:— (1) Nimonic alloys and cobalt-base alloys; (2) heavily-alloyed austenitic steels; (3) austenitic steels of lower alloy content; and (4) ferritic steels of medium-to-high tensile strength. Recommendations are made, in these categories, for conditions for turning and boring, milling, broaching, tapping, drilling and reaming. Grinding

procedure is also described, with a table showing grinding wheels suitable for various operations.

The use of surface-coated abrasives is becoming increasingly usual, for finishing operations after machining, and in this connexion details are given of suitable grits, methods of application and cutting fluids. Brief reference is also made to filing.

Improvements in machining properties of the high-temperature steels and alloys are being effected by two methods: (1) addition of elements which facilitate chip formation by modifying the phases present in the material, and (2) by special heat-treatments developed to put the materials into a more machinable condition. The authors give a table showing the effect of free-machining additions (sulphur and selenium) in 18-8 steel, and illustrate the influence of heat-treatment by reference to modifications so produced in the (cobalt-base) austenitic steel G.32. The limitations of both methods, in respect of possible adverse effects on other properties, are noted.

The final section of the paper contains some practical suggestions for improvement of machining quality of the high-temperature materials, and notes on methods which may be used to facilitate machining practice.

VII. Special Blade Materials

E. A. G. LIDDIARD and A. H. SULLY: 'Chromium-base Alloys for Gas-Turbine Applications,' pp. 243-5.

The advantages of chromium as a material for large-scale high-temperature use are reviewed and the reasons which have militated against the use of chromium-rich alloys are summarized.

Melting and casting techniques essential for production of chromium-base materials are discussed, and alternative methods of production are considered. Properties obtainable in chromium-base alloys include a high degree of creep-resistance, and good resistance to oxidation, but the room-temperature brittleness inherent in these materials at present precludes their use for engineering applications. Work in hand at the Fulmer Research Institute and elsewhere is concerned with ascertaining whether the brittleness is an intrinsic property of chromium or whether it is due to traces of a particular impurity. Elimination of this inhibiting characteristic would substantially widen the field of application of chromium-base materials.

J. C. CHASTON and F. C. CHILD: 'Some Cobalt-rich Alloys for High-Temperature Service,' pp. 246-8.

The authors report examination of the stress-rupture characteristics, at 900°C., of some precision-cast alloys in the tantalum-chromium-cobalt system. Particular attention is directed to the influence of carbon on the creep behaviour and microstructure of alloys containing tantalum 10, chromium 10, per cent. Optimum results were found with a carbon content of about 0·3 per cent. It is believed that raising the tantalum and chromium contents to 15 per cent. each would still further improve the creep resistance.

H. J. GOLDSCHMIDT: 'Phase Diagrams of the Ternary Systems Fe-Cr-W, and Fe-Cr-Mo at Low Temperatures,' pp. 249-57.

Phase relationships in these systems were investigated by X-ray analysis for a 600°C. equilibrium, using powder-diffusion methods. The author pays particular attention to the behaviour of the sigma and xi phases (which are largely competitive and tend to inhibit each other), and of the primary alpha solid solutions: the latter form miscibility bays with potential precipitation-hardening effects.

The compound FeMo, existing in the iron-molybdenum binary system at high temperatures (above 1180°C.), is retainable by quenching. It shows sigma structure, and forms a series of solid solutions with FeCr. In contrast to the latter, it is stable up to its melting point.

Practical uses for alloys in these two groups are indicated, with particular reference to compositions which, on structural grounds, hold promise for use as heat-resisting materials.

An appendix to the paper contains a short discussion of existing knowledge on the crystal structure of sigma.

R. W. A. BUSWELL, W. R. PITKIN and I. JENKINS: 'Sintered Alloys for High-Temperature Service in Gas Turbines,' pp. 258-68.

A cobalt-base alloy of the Vitallium group, containing chromium 30, tungsten 6, per cent., has been successfully used in the cast state as a blading material. The investigation reported in this paper comprised an examination of an alloy of similar composition, prepared by powder-metallurgy methods, to determine to what extent the properties of the cast alloy could be duplicated in sintered material.

The report shows that, with correct blending of powders of suitable characteristics, and by ensuring adequate control of sintering conditions, it is possible to produce, from powders, a high-quality product which, in the as-sintered condition, shows a density close to the absolute density of the cast alloy.

The room-temperature properties of the sintered Vitallium alloy compared favourably with those of the cast material, and high-temperature fatigue properties were satisfactory, but the overall strength of the sintered material, particularly in creep, was low at temperatures above 600°C. The possibility of improving its high-temperature properties by addition of carbon, or by introduction of refractory oxides such as thoria, is discussed. The sintered alloys were found to be highly sensitive to heat-treatment. The effect of ageing, on mechanical properties, was investigated, and the significance of crystallographic transformation during ageing is considered.

T. G. CARRUTHERS and A. L. ROBERTS: 'Ceramics as Gas-Turbine Blade Materials—A Survey of the Possibilities,' pp. 268-72: see also *Aircraft Production*, 1951, vol. 13, pp. 88-91.

The main purpose of the paper was to discuss known properties of refractory ceramics, with a view to assessing their potential value as materials for gas-turbine components, and to indicate to what extent the deficiencies in their properties, for such purpose, may be remedied.

Following some observations on the characteristics of ceramics in general, the authors give specific data on the properties, at room temperature and at elevated

temperatures, of the following sintered oxides: Al_2O_3, BeO, MgO, ZrO_2, ThO_2, $MgO.Al_2O_3$ (spinel). A later section of the paper gives similar data for some multi-component ceramics: silicon carbide/clay, BeO-MgO-ZrO_2 and other mixtures.

Critical consideration of the properties of these materials leads to the conclusion that the single-component types have some potential value for use in turbine blading, at temperatures up to 1000°C., provided that they are not subject to thermal shock. Their poor resistance to alternating temperature would preclude their use in intermittently operated engines. Multi-component ceramics appear to be more susceptible to improvement in respect of resistance to thermal shock, but lack of availability and manufacturing problems associated with these materials may bar their application. Metal-ceramic mixtures may prove to offer some solution to the problem.

L. ROTHERHAM, W. WATT, J. P. ROBERTS and F. J. BRADSHAW: 'Ceramics for Gas Turbines,' pp. 273-80.

This paper is concerned specifically with the preparation of sintered alumina and the measurement of its properties. A detailed account is given of production methods, technique of testing, and general mechanical and physical characteristics of the sintered product.

The results show that at 1000°C. sintered alumina has a bend strength and creep properties superior to those of any metallic material currently in use, but that its tensile properties are unsatisfactory. Sudden heating or cooling under conditions equivalent to those obtaining in gas-turbine service causes failure due to stresses set up by unequal temperature distribution, and a theoretical study of thermal shock in brittle materials leads to the tentative conclusion that they are unlikely to survive the conditions existing in a gas turbine. In this paper also it is suggested that the degree of ductility imperative for such service may be obtained by the use of metal-ceramic mixtures.

P. GROOTENHUIS and N. P. W. MOORE: 'Sweat-Cooling —A Review of Present Knowledge and its Application to the Gas Turbine,' pp. 281-8.

Although it is generally acknowledged that the performance of gas turbines can be improved by raising the maximum temperature in the cycle, such method of improvement is limited by the high-temperature properties of materials of construction at present available. Considerable increase in operating temperature can therefore be accepted only by more efficient cooling, for which various methods have been suggested.

This paper defines the essential features of sweat cooling, discusses the mechanism by which it can be effected, and reviews the properties necessary in a sweat-cooled component. It is suggested that these requirements can best be met by special methods which will utilize the properties of cooling equipment made by powder-metallurgy methods. Relation between porosity and permeability is examined, and relevant published data are reviewed.

Problems involved in production of turbine blades suitable for sweat cooling are considered and some designs are tentatively suggested. This method of cooling has already been shown to have advantages, and work is currently in progress on heat transfer, flow, and aerodynamic aspects of the subject.

VIII. Research and Future Needs

C. A. BRISTOW and H. SUTTON: 'Research and Development on High-Temperature Materials,' pp. 289-92.

At the outset of this paper attention is directed to the practical importance of availability as a factor determining selection of materials of construction to be used in large-scale production of gas turbines. The increasing use of metals, in a world of constantly rising population, calls for avoidance of misuse, wastage and loss, especially in the case of the less-abundant metals, such as cobalt and niobium. To illustrate the position, tables are given showing (1) the relative abundance of the various metals in the earth's crust, and (2) world production of some important metals and minerals in 1946. Methods of rating the respective metals, in relation to their strategic importance, are considered.

As a second major factor, metallurgical considerations governing choice of materials for high-temperature use are reviewed. These include high melting point, density, and resistance to creep, fatigue, surface deterioration and embrittlement at high temperatures; resistance to thermal shock, and good fabricating qualities. Some of the materials currently in use or under experimental study for gas turbines are briefly reviewed, with an indication of subjects which require further study.

It is pointed out that basic metallurgical information on the constitution of alloy systems is urgently needed, not only as a means of developing new alloys, but also in the interests of improving existing types. The alloy systems known to be under intensive study in Great Britain are listed, with an indication of the research laboratories in which the respective groups are being investigated.

J. M. ROBERTSON: 'Future Needs in Materials for Land and Marine Gas Turbines,' pp. 293-303.

The general theme of this concluding paper is that progress in gas-turbine development depends on a complicated system of relationships among those who (1) develop and produce materials, (2) make components, (3) design and build turbines, (4) buy and operate turbines, and (5) carry out laboratory work on which the introduction of new materials and the understanding of existing ones depend. None of these groups can, independently, make much contribution to progress. The writer suggests directions in which research, development, study, and accumulation of knowledge and experience may proceed on a co-operative basis. In brief, the imperative need is for continued progress in gas-turbine metallurgy, associated with progress in gas-turbine engineering, and taking this idea as a basis, the author reviews the factors which are of major importance from (*a*) the metallurgical, and (*b*) the design and operation standpoints.

Factors involved in the use of metals in gas turbines are considered in four categories: (1) service performance,

(2) making, shaping and treating, (3) conditions of use, and (4) cost of components. In the light of the requirements under (1)-(4), a review is made of the *range of materials now available* to the gas-turbine builder. Ferrous and non-ferrous materials already used, or potentially suitable, are listed in 11 classes, passing from aluminium alloys used for components operating at normal or slightly elevated temperatures, through to the nickel- and cobalt-base alloys used for blading and other high-temperature components, and to metallic and non-metallic materials still only in the experimental stage of development.

Operating conditions in which land and marine gas turbines are required to function are then considered, with particular reference to service temperatures; due reference is also made to the importance of the stress imposed on a component operating at any given temperature.

Finally, a survey is made of materials, in relation to the production and properties of individual components. Current practice and some needs for future improvement are considered as affecting blades, discs and rotors, heat exchangers, combustion chambers and flame tubes, cylinders, casings and other parts.

End of Symposium

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Investment Casting of Nickel-containing Materials: Study of Pre-Coats

W. F. DAVENPORT and A. STROTT: 'Pre-coat Materials for Investment Casting.' *Amer. Foundrymen's Soc., Preprint* 51-27, Apr., 1951; 8 pp.

The programme under which this work was done was initiated in order to evaluate some of the more plentiful oxides as pre-coating materials. Various ceramic oxides, alumina, silica, zirconium silicate and magnesia were studied. These materials were assessed on the basis of the following qualities, considered as essential in an ideal pre-coat material; simplicity of preparation, economy in cost of material, physical and chemical inertness, resistance to thermal cracking, and adherence of reaction products, if any, to the investment rather than to the casting.

The casting materials chosen were stainless steel, Type 302; a nickel-chromium-molybdenum steel of S.A.E. 4340 type, and a heat-resisting alloy containing chromium 20, nickel 40, carbon 0·5, silicon 0·5, manganese 1·0, per cent., cobalt remainder.

The results, which are recorded in detail and well illustrated, indicated that the alumina-silica group (in the range 60-90 silica, 40-10 alumina) offered the greatest promise: optimum compositions within this range varied with the material cast. Mixing procedure for these composites presents some difficulties, but investigations by the authors showed that a combination of polyvinyl alcohol and sodium silicate is a satisfactory binder. Pre-coats of zirconium silicate were found to be comparable to the standard silica-flour pre-coat; magnesia compositions all gave poor results.

The work described was done in the laboratories of Air Materiel Command at Wright-Patterson Air Force Base, Dayton, Ohio, and in a related paper (*Iron Age*, 1951, vol. 167, Apr. 19, pp. 90-4) the same authors give a practical account of some of the precision-casting techniques which have been developed in that laboratory, and of their application in a small experimental foundry, in the casting of heat-resisting alloys.

Machining of Nickel and Nickel-containing Materials

N. E. WOLDMAN and R. Ç. GIBBONS: 'Machinability and Machining of Metals.' *Published by McGraw Hill Book Co., Inc.*, New York and London, 1951; 518 pp. Price 25/-.

The aim of the book is two-fold: to acquaint the reader with the metallurgy and machining characteristics of metals and their alloys, and to familiarize him with machining practice in general, and specialized techniques suitable for handling individual materials. The treatment of the subject is both theoretical and practical, and the recommendations made are based on laboratory experiment and plant-production experience.

Introductory chapters cover the principles of machining, the mathematical aspects of the subject, and cutting tools and their design. These are followed by chapters dealing with machining of the following materials: steel; ingot and wrought irons, and low-carbon steel; plain medium- and high-carbon steels; alloy steels, tool and die steels; stainless steels; cast iron; aluminium alloys; magnesium alloys; copper alloys; nickel alloys; zinc alloys; special metals and alloys, non-metallic materials. The final chapter contains a discussion on cutting fluids, their function, composition and characteristics, and mode of use. In discussing the machining of nickel alloys, the author has drawn largely on the publications of The International Nickel Company, to whom acknowledgment is made.

Brazing of Nickel-containing Materials

BRIT. STANDARDS INSTN.: 'Brazing.' *B.S.* 1723; 1951.

This Standard, which is complementary to B.S. 1725 'Bronze Welding by Gas', has been prepared as part of the programme of welding standards authorized by the Welding Industry Standards Committee of the Institution.

The Standard covers joints and connexions made by brazing, using one of the following heating media: blowpipe, furnace, electric-induction, electrical-resist-

ance, dip, and salt bath. It relates to brazing of the following parent metals: copper, copper-base alloys, mild steel, carbon steels, alloy steels, stainless steels and irons, malleable and wrought iron, cemented carbides, nickel-base alloys, and aluminium and certain aluminium alloys. Combinations of parent metal and filler metals are conveniently tabulated, and essential details of equipment and technique are given. Other sections cover joint design and preparation, fluxes and flux removal, and test procedure. The appendix contains illustrations of typical oxyacetylene flames (oxidizing, neutral and reducing).

Lukens Steel Company: Practice and Products

See abstract below.

NICKEL

Production of Nickel-Clad Steel by Lukens Steel Company

'From Ingot to Weldment.' *Welding and Metal Fabrication*, 1951, vol. 19, May, pp. 167-73.

The article is the eighth in a series describing some outstanding metallurgical and metal-working organizations in the U.S.A. It gives an account of the plant, processes and general activities of Lukens Steel Company, where routine production covers all processes from steel melting to inspection and finish-machining. As typical of the products of the firm, the following are specifically mentioned: production of wide plate (up to 195 in. wide); supply, to vessel makers, of spun dished ends up to 246 in. in diameter; production of a comprehensive range of nickel-, nickel-alloy- and stainless-clad steels; contract cutting of steel shapes for the fabricating industries; designing and fabrication of steel plate structures by welding (in the Lukenweld division). Some of the major features of equipment and production technique used in the respective workshops are described and illustrated.

Spectrophotometric Analysis of High-Nickel Alloys

R. BASTIAN: 'Differential Spectrophotometric Determination of High Percentages of Nickel.' *Analytical Chemistry*, 1951, vol. 23, Apr., pp. 580-6.

Accurate determination of nickel in high-nickel alloys (e.g., 98 per cent., as used in the electronic industry) is difficult when using conventional methods of analysis. This paper proposes a differential colorimetric procedure by which nickel can be determined to about $\pm 0{\cdot}05$ per cent. in such materials. It is also possible to determine, simultaneously, cobalt to an approximate accuracy, and small amounts of chromium.

The method is based on the use of the green colour of nickel in perchloric-acid solution. Concentrated nickel solutions are read on the Beckman Model DU spectrophotometer, using a similar standard in the comparison cell. Procedure for determining the optimum concentration of the standard is given. Under correct conditions, a precision 13-14 times that obtainable by normal colorimetry is theoretically possible by the new method. Its use is demonstrated by reference to estimation of nickel in the type of metal used in the electronic industry, in nickel of spectrographic purity, and in synthetic mixtures containing copper, chromium, iron and cobalt. Full details of procedure are given, together with report on investigation of the influence of all possible variables in working conditions and the interference of other metals.

Determination of Nickel in Effluents

P. G. BUTTS, A. R. GAHLER and M. G. MELLON: 'Colorimetric Determination of Metals in Industrial Wastes.' *Metal Finishing*, 1951, vol. 49, Apr., pp. 50-60, 63.

Discharge of metallic wastes from electroplating plants and other metal-processing industries has become a matter of serious concern to public health authorities in many areas, but investigations of problems associated with stream pollution have been handicapped by lack of suitable analytical methods for determination of the heavy metals involved.

In order to overcome this difficulty, a programme was drawn up, under the auspices of the Federation of Sewage and Industrial Wastes Associations, for development of methods for estimation of cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc, in sewage and industrial wastes. This paper presents details of colorimetric methods for determination of all these metals; the procedures are designed to allow estimation of as little as $0{\cdot}05$ mg. ($0{\cdot}05$ p.p.m.) of the ion in question, in a1 -litre sample, and are applicable in presence of the other heavy metals listed, in amounts up to at least 200 times the concentration of the constituent to be estimated. Allowance is also made for the presence of organic matter and such anions as may commonly be found in polluted water. Detailed procedures are given for preliminary treatment of the sample, qualitative identification of the heavy metals present, and quantitative analysis by photoelectric colorimetry.

'*Nickel* can be detected if present in a concentration of not less than 1 p.p.m. in a solution containing 10 p.p.m. each of cadmium, chromium, copper, iron, lead, manganese and zinc. The concentration limit for nickel varies, depending on the amount of copper and manganese present.

'*Procedure*. A drop of solution containing the reagent is placed on No. 601 S and S test paper, then a drop of the test solution. If manganese is present, a black fleck appears. It is advisable to compare this spot with a blank.

'Actually this spot test offers no advantage over the quantitative method for determining manganese. The quantitative method is quite sensitive and it takes only a few minutes to develop the permanganate colour (see *Feigl*: 'Qualitative Analysis by Spot Tests', p. 137 (1946).'

Quantitative estimation of nickel is carried out with 2-cycloheptanedionedioxime (heptoxime); see next abstract. Iron and copper are removed by extraction of the cupferrates with chloroform. The nickel is

separated from other ions by extraction of the nickel heptoxime complex with chloroform, re-extracted into the aqueous phase with hydrochloric acid, and determined in the acidic solution with heptoxime in the presence of an oxidant. Full details of apparatus required and of procedure are given.

Determination of Nickel in Calcium

R. C. FERGUSON and C. V. BANKS: 'Spectrophotometric Determination of Nickel in Calcium Metal using 1,2 Cyclohexanedionedioxime.' *Analytical Chemistry*, 1951, vol. 23, Mar., pp. 448-53.

In an introductory survey of earlier literature on determination of nickel, the authors observe that approximately 125 papers published since 1900 have dealt with the colorimetric, photometric or spectrophotometric determination of this element. Some of the major contributions are briefly noted.

Review of existing information appeared to indicate that the *vic*-dioximes offered possibilities in this direction and this paper records the authors' investigations in this connexion. It is observed that the reactions of 1,2-cyclohexanedionedioxime (nioxime), and 1,2 - cycloheptanedionedioxime (heptoxime) with nickel in presence of an oxidizing agent in alkaline solution are similar to the reaction of dimethylglyoxime, in that in each case unstable, reddish-brown colours are produced, having absorption spectra which are very similar.

It is possible, however, to stabilize the red inner complex compound of nickel (II) with 1,2-cyclohexanedionedioxime with gum arabic. The compound is insensitive to changes of pH, absorbs more strongly at 550 mu, and conforms to Beer's law.

The applicability of this method, to the spectrophotometric determination of nickel, was established: very full details of procedure are given. The effects of various foreign ions are discussed and the method is demonstrated by application to estimation of nickel in calcium. The simplicity of the procedure is urged as a particular advantage for routine purposes. Few preliminary separations are required, and some of the extractions essential in some other procedures are eliminated. Accuracy and reproducibility are adequate for the purposes of trace analysis.

Alpha-Furildioxime as Reagent for Determination of Nickel

A. R. GAHLER, A. M. MITCHELL and M. G. MELLON: 'Colorimetric Determination of Nickel with Alpha-Furildioxime.' *Analytical Chemistry*, 1951, vol. 23, Mar., pp. 500-3.

The authors report a study of the conditions in which nickel may be determined colorimetrically with alpha-furildioxime, with particular reference to the comparison of this method with procedures using dimethylglyoxime or 1,2-cyclohexanedionedioxime (see preceding abstract).

The nickel alpha-furildioxime complex is a usable form of compound for determination of nickel, after extraction of the coloured complex with 1, 2-dichlorobenzene. This possibility of extraction facilitates separation of the metal from coloured interfering solutions, such as iron and chromate salts. Careful regulation of pH of the solution is necessary, but otherwise it has satisfactory colorimetric properties, and the excellent extractability of the complex is noteworthy, in comparison with that of oxidized nickel dimethylglyoxime. It is considered that the method has some advantages over the earlier dioxime processes.

The applicability of the procedure described is demonstrated by reference to determination of nickel in (1) a standard N.B.S. steel containing 0·196 per cent. of nickel, in association with small percentages of copper and chromium, and (2) a magnesium alloy containing 0·0024 per cent. of nickel, accompanied by 6·35 per cent. of aluminium and small percentages of copper, iron, manganese, silicon and zinc.

Properties of Age-Hardening Nickel-base Alloys

See abstract on p. 132.

Machining of Nickel and Nickel-containing Materials

See abstract on p. 128.

ELECTRODEPOSITION AND OTHER COATING METHODS

Cleaning of Metals Prior to Electroplating: A.E.S. Research Project

H. B. LINFORD and E. B. SAUBESTRE: 'Cleaning and Preparation of Metals for Electroplating. II. Soiling and Cleaning Procedures.' *Plating*, 1951, vol. 38, Apr., pp. 367-77.

Report of laboratory investigations carried out under A.E.S. Research Project 12, December 1949, to April 1950.

The nature of the problem of soiling and cleaning metals in the laboratory is reviewed. Cleaners, soils, and metals to be used in the experiments are discussed, also the shape and size of the test panels, and methods of preparation of the samples.

A standardized procedure for pre-cleaning, soiling, and re-cleaning panels, prior to testing, is proposed. Results are given of gravimetric tests made to determine the soil present on test panels subjected to various soiling treatments, and the influence of variables in soiling materials and procedure are evaluated.

Modern Electroplating Plant

A. F. BROCKINGTON: 'Modern Electroplating Plant. Equipment for Plating with Nickel, Chromium, Silver, Gold, Brass and Copper.' *Brit. Engineering*, 1951, vol. 33, May, pp. 1087-92.

A well-illustrated review. *Inter alia*, attention is directed to important developments which have taken place during the past few years in connexion with electrodeposition of nickel (use of addition agents, insistence on better purification of solutions, introduction of bright-plating baths). All these modifications have, in one way or another, influenced the design and materials of construction used in plating plant;

some of the improvements are described, e.g., filtering equipment used with various types of bath, and automatic bright-plating plant.

Nickel Plating in the U.S.A.

W. H. PRINE: 'Industrial Nickel Plating in the United States.' *Metal Industry*, 1951, vol. 78, May 11, pp. 383-8.

The importance of the nickel-plating industry in the U.S.A. is indicated by the fact that in 1949 approximately 28,000,000 lb. of nickel were consumed by it. This article gives an up-to-date picture of present practice, grouping the uses of nickel-plating in the following five divisions: decorative plating, for appearance and protection against corrosion; plating for salvage and building up of undersize parts; heavy industrial plating, to secure corrosion-resistance; plating of non-conducting materials; electro-forming.

The information given is essentially of a practical and reference type, including tables showing compositions of solutions and plating conditions used for production of coatings of the various types, hardness and mechanical properties obtained from deposits made from baths of various compositions, and cycles recommended for pre-treatment of ferrous and non-ferrous materials on which decorative or industrial types of coating are to be deposited. Specifications for coatings used in the automobile industry are also discussed.

The article is illustrated with photographs showing typical uses of the various grades of coating, indicating the wide range of industries in which nickel plating plays an important rôle.

Nickel Plating of Aluminium and its Alloys

J. M. BRYAN: 'Plating Aluminium with Nickel.' *Metal Industry*, 1951, vol. 78, May 18, p. 405.

An etching process* developed in the laboratory of the Low-Temperature Research Station, Cambridge, for preparing the surface of aluminium for plating, proved impracticable for commercial application. The high concentration of trichloroacetic acid required in the etchant rendered it too costly, and the use of acetone for washing the aluminium between etching and plating involved risk of fire. Further investigation has shown that addition of 25 per cent. of phosphoric acid to the etchant permits reduction of the trichloroacetic acid to 5 per cent., and that a dip in 20 per cent. nitric acid allows the use of water, in place of acetone, for washing. These modifications have still to be tested on a commercial scale. Full particulars are given of the procedure proposed.

E. E. HALLS: 'Electroplating Aluminium and Aluminium Alloy Components. Part I. Study of Pre-Treatments and Dipping Processes. Part II. Electrolytes for Various Processes.' *Metal Treatment and Drop Forging*, 1951, vol. 18, Mar., pp. 125-31; Apr., pp. 177-82.

Part I comprises a short discussion of the difficulties involved in plating aluminium-base materials, and a summary of the main features of pre-treatment processes which have been proposed for preparation of the surface for plating.

Part II contains notes on compositions of baths, and procedure which may be used for electrodeposition, on prepared surfaces, of copper, nickel, chromium, silver, tin, gold and rhodium.

An appendix records some tests of durability of electrodeposited coatings on aluminium and aluminium alloys under exposure to (1) cyclic dry and hot-humid conditions; (2) salt spray. The coatings exposed were of the following types: nickel + chromium, copper + silver, copper + nickel.

*See *Nickel Bulletin*, 1950, vol. 23, No. 5, p. 83.

Commercial Plating of Automobile Parts

'Accessory Manufacture. The Production Methods at the Works of Wilmot Breeden, Ltd.' *Automobile Engineer*, 1951, vol. 41, May, pp. 171-81.

The article describes outstanding features of nine divisions of the Wilmot Breeden factory, the main products of which are bumpers, locks, window regulators, handles, steering wheels, and interior fittings. The description includes an account of operations used in polishing and plating bumper bars, which are finished with a nickel + chromium coating, and of plating of the handles, which are zinc-base die castings, coated with copper + nickel + chromium.

Conservation of Nickel Salts in Nickel-Dip Process

J. M. ZANDER: 'Conservation of Nickel Salts in the Vitreous Enameling Industry.' *Better Enameling*, 1950, vol. 21, Dec., pp. 6-7.

Practically all enamelling plants, and especially those using medium- or low-temperature enamels with various grades of steel, depend on the use of a nickel-flash treatment to ensure satisfactory adhesion. This article is a practical one, designed to aid enamellers in conserving, and using to best advantage, the restricted supply of nickel salts now available for the dip treatment.

(1) *Nickel-Salt Concentration*

Use of excessively high concentrations of nickel salts, e.g., 2-4 oz./gal., offers no particular benefits, and results in high consumption from drag-out. Weights of nickel deposit within the limits necessary to obtain adequate adherence can be secured with concentrations of nickel salts of 1-2 oz./gal. This can be attained by lengthening the time of immersion, or operating the bath at much higher temperature, or both, while maintaining the nickel solution at a pH of 3-4. If longer time of immersion interferes with production schedules, the same result can be achieved by rinsing with hot water. instead of cold, between the sulphuric-acid and the nickel baths, thus lessening the time required for the work, when placed in the nickel bath, to reach the temperature at which maximum deposition takes place.

(2) *Cyanide Neutralizers*

Although the use of a cyanide neutralizer aids in removal of bloom from pickled ware, it also has the disadvantage of removing some of the nickel, making

it necessary to deposit, initially, a weight of nickel in excess of that required to ensure adherence. Complete elimination of a cyanide neutralizer, or reduction in cyanide concentration, would help to conserve nickel salts, and to this end adjustments in the pickling and cleaning procedure may be made. A weak sulphuric-acid rinse (0·15-0·25 per cent.), in place of the conventional rinse, after the nickel bath, is recommended.

(3) *Dumping of Partially Spent Nickel Solutions*

It is very usual practice periodically to discard nickel baths as a precautionary measure, even though efficient filtering units are provided for removal of insoluble iron hydrate or basic sulphate. This practice is strongly deprecated. Such baths can be operated almost indefinitely, provided that precautions are taken to avoid contamination from oil, etc., and that only single nickel salts, caustic, and sulphuric-acid solutions are used to maintain strength of the bath and its correct pH. In plants operating without a filter, iron-contaminated baths can be reclaimed by adding sodium hydroxide to maintain a pH of about 5, and heating the bath to boiling, with vigorous air-agitation, for 4-6 hours. Iron in solution will precipitate or coagulate out and can be separated at the bottom of the tank when agitation and heating have ceased. The nickel solution is pumped or siphoned into the nickel-rinse tank, the iron sludge is removed, and the cleared nickel solution is replaced in the nickel-plating tank and adjusted to correct strength and pH. The author strongly advocates provision of filters, urging that savings in nickel salts will pay for such installation in a very short period of operation.

See also following abstract.

PORCELAIN ENAMEL INST.: 'Test for the Determination of Nickel. A Tentative Standard Test.' Published by the Institute, 1951; 8 pp.

Details are given of method of removal of sample from a stopped-off portion of the surface (by treatment of nitric and with hydrochloric acid), and determination of nickel by a photometric method. The procedure is considered to be sufficiently accurate for use as a routine control method.

Corrigendum

Nickel Bulletin, Apr., 1951, p. 74.

In Table I, column 2, in composition of copper-electroforming bath, for 'Sulphuric acid 65 oz./gal.' *please read* 'Sulphuric acid 6·5 oz./gal.'

NON-FERROUS ALLOYS

Properties of Age-Hardening Nickel-base Alloys

INTERNATIONAL NICKEL CO., INC.: 'Age-Hardening Inco Nickel Alloys.' **Tech. Bull. T.*16, Jan., 1951; 19 pp. See also W. A. MUDGE, 'Age-Hardenable High-Nickel Alloys.' *Metal Progress*, 1951, vol. 59, Apr., pp. 529-36.

This bulletin gives details of the treatment and properties of the materials shown in the table below:—

Alloy	Nominal Composition, %											
	Ni	Cu	Fe	Mn	Si	Cr	S	C	Nb	Al	Ti	Mg
'K' Monel	66	29	0·9	0·75	0·5	—	0·005	0·15	—	2·75	0·5	—
'KR' Monel	66	29	0·9	0·75	0·5	—	0·005	0·25	—	2·75	0·5	—
'S' Monel	63·5	29·5	2	0·8	4	—	0·015	0·1	—	—	—	—
Duranickel	93·7	0·05	0·35	0·3	0·5	—	0·005	0·17	—	4·4	0·4	—
Perma-nickel	98·5	0·03	0·1	0·2	0·15	—	0·005	0·25	—	—	0·4	0·35
Inconel 'X'	73	0·05	7	0·5	0·4	15	0·007	0·04	1	0·9	2·5	—

Physical constants of the alloys are tabulated and details are given of thermal treatments (for softening, age-hardening, and stress-equalizing), furnace and container equipment suitable for the respective heat-treatments, and atmospheres for bright and semi-bright treatment. Supplementary notes relate to methods for removal of sulphur and of oxygen from gases to be used in heat-treatment; procedure for dewpoint determination and for drying of gas atmospheres; gas generators and convertors; purging of gas atmospheres and their maintenance; methods of temperature control in thermal treatment, and the importance of protecting the alloys from contamination by foreign material during processing.

INTERNATIONAL NICKEL CO., INC.: 'Engineering Properties of Duranickel.' *Technical Bull. T.* 32, 1951; 20 pp.

In this Bulletin a more closely detailed account is given of the properties and processing of a nickel-aluminium-base alloy developed to provide the corrosion-resistance characteristic of nickel, combined with a higher degree of strength and hardness. The data include much information (presented largely in tabular and graphical form) on mechanical properties, at both normal and elevated temperatures; working

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characteristics, and recommendations for processing; thermal treatment and corrosion-resistance. Typical applications of Duranickel are also described and illustrated.

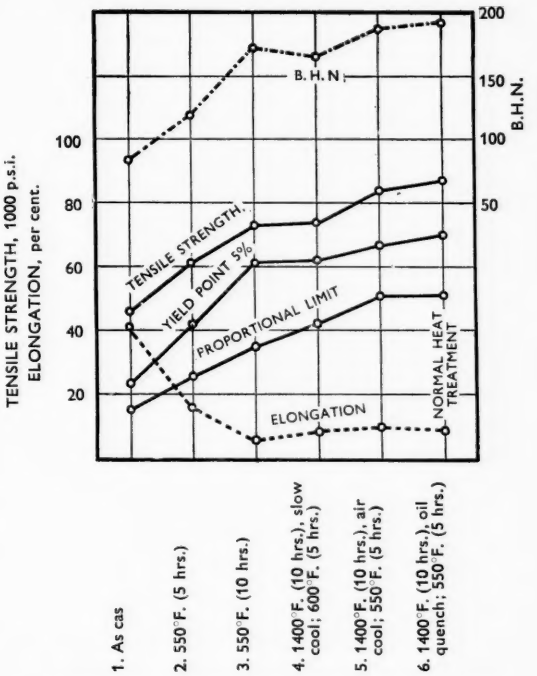
The composition and properties of Permanickel (see p. 132) are also recorded, and methods of test for distinguishing between the two precipitation-hardened nickels are described.

Nickel Additions in Copper-base Alloys

J. S. VANICK: 'The Nickel-Tin Bronze Theory.' *Foundry*, 1951, vol. 79, Apr., pp. 130-3, 278-9.

This article, the fifth in the series reviewing the properties of brass and bronze alloys containing small amounts of nickel, is primarily a supplement to the survey of the nickel-tin bronzes published *ibid.*, Feb., 1951; see *Nickel Bulletin*, 1951, vol. 24, No. 4, p. 77. It is based mainly on the work of Kihlgren, Eash and Upthegrove, Eash and Wise, and Price, Grant and Phillips, to whose original reports reference is given in the *bibliography*.

The present article is essentially a discussion of the fundamental reasons why the addition of nickel in the 'Ni-Vee' (nickel-tin) bronzes produces the effects observed. The modifications resulting from the presence of nickel are due, primarily, to the fact that nickel and tin form a constituent which is completely soluble in the liquid metal but has only limited solubility in the solidified metal, thus making possible the advantages resulting from precipitation hardening effected by thermal treatment. Phase relationships in the nickel-tin system, at various temperatures, are graphically illustrated, and the mechanism of the strengthening and hardening effects producible are considered in some detail. Diagrams demonstrate the influence of time and temperatures of treatment, on copper-base alloys containing various percentages of nickel and tin.



The following properties may be regarded as typical of those producible in the three representative Ni-Vee alloys described.

Attention is again drawn to the deleterious influence of lead in these alloys.

A diagram 'designed to summarize all the important features of the heat-treatment of Ni-Vee bronzes', has been prepared on the basis of correlated information obtained from the work of all investigators who have studied this range of materials. It is reproduced above.

Mechanical Properties of Nickel-Bronze Alloys, As Cast and Heat-treated

* Composition		Heat-Treatment				Ultimate Tensile Strength		Proportional Limit		Yield Strength (0·2% Permanent Set)		Elongation % in 2 in.	Reduction of Area %	Brinell Hardness No.
		Annealing (Water Quenched)		Ageing (Quenched)										
% Ni	% Sn	°F.	Hrs.	°F.	Hrs.	p.s.i.	t.s.i.	p.s.i.	t.s.i.	p.s.i.	t.s.i.			
—	—	No heat-treatment				25,900	11·6	4,000	1·8	9,000	4·0	57	68	43
5	5	No heat-treatment				48,850	21·8	13,500	6·0	22,800	10·2	44	50	75
		1400	10	500	5	74,000	33·0	40,000	17·9	53,000	23·7	27·5	29	136
		1400	10	600	5	84,000	37·5	47,500	21·2	66,000	29·5	16	26	171
7·5	5·5	No heat-treatment				56,500	25·3	24,000	10·7	29,400	13·1	36	34	—
		1400	5	500	10	86,300	38·5	50,000	22·3	64,500	28·8	22·5	34	165
		1400	5	650	5	103,900	46·4	62,000	27·7	—	—	5	8	213
7·5	8	No heat-treatment				58,000	25·9	25,000	11·2	34,000	15·2	18	18	105
		1400	5	500	5	89,650	40·0	55,000	24·6	76,000	33·9	18	34	179
		1400	10	600	5	111,150	49·6	66,000	29·5	—	—	6	7	228

* All alloys listed above contain 2 per cent. zinc.

Monel Stays in British Railways Standard Locomotives

'Standard 4-6-0 Mixed Traffic Locomotives.' *Engineer*, 1951, vol. 191, May 4, pp. 576-7.

Description of the first of the new engines of this class, the 73,000, which was recently completed at the Derby Works. As in the 70,000, representative of the 4-6-2 class, all firebox water space stays are of Monel.

Machining of Nickel and Nickel-containing Materials

See abstract on p. 128.

Corrosion-Resisting Materials in Marine Engineering: Review

See abstract on p. 144.

Nickel-Manganese-Silicon Sparking-Plug Alloys

MOND NICKEL CO., LTD.: 'Silicon-Manganese-Nickel Alloys; W. 6 and W.7.' **Publn.* 502, 1951; 4 pp.

Service experience has shown that under the conditions obtaining in modern internal-combustion engines using anti-knock fuels, high-nickel alloys containing small amounts of silicon and manganese are more resistant than other commercially available materials. This publication tabulates the physical and mechanical properties of two alloys developed for this purpose, having silicon-manganese ratios varied to meet the specific requirements of individual makers of sparking plugs.

The alloys are designated W.6 (manganese 0·5, silicon 2·0, per cent., balance nickel), and W.7 (manganese 2·75, silicon 1·0, per cent., balance nickel). Both may be used for the centre and earth electrodes on all types of sparking plug at present in supply: both can be projection- or spot-welded to the steel body of the plug. The alloys are produced as wire, strip, or rolled tape.

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NICKEL-IRON ALLOYS

Thermal Expansion of Invar: Influence of Impurities

B. S. LEMENT, C. S. ROBERTS and B. L. AVERBACH: 'Determination of Small Thermal Expansion Coefficients by a Micrometric Dilatometer Method.' *Rev. Scientific Instruments*, 1951, vol. 22, Mar., pp. 194-6.

Two methods have, to date, been used for measurement of the coefficient of thermal expansion of Invar (in which problems of an unusual character arise due to the small length changes involved): (1) the micrometric, and (2) the interference method.

The present authors have modified the micrometric method to a more convenient form: the equipment and technique used are described, with drawing of the instrument.

To demonstrate the results obtainable, graphs are given illustrating the measurement of expansion coefficient of a commercial free-cutting Invar, a high-purity Invar, and a fused quartz. In the cold-drawn condition the expansion coefficient, α, of the free-cutting alloy is approximately 2×10^{-6} °C.$^{-1}$. After water quenching from 830°C. the value is reduced to about 1×10^{-6} °C.$^{-1}$ The free-cutting Invar contained carbon 0·07, selenium 0·16, manganese 0·9, per cent., and the values in Table 1 below show that the presence of such impurities adversely affects the minimum expansion coefficient which can be obtained by heat-treatment. In a high-purity Invar the coefficient can be reduced to practically zero over the range −40° to +40°C.

Coefficient of Thermal Expansion of Invar

Composition				Annealed (*a*)	Expansion Coefficient × 10^6/°C. (−40 to +40°C.)	
C %	Mn %	Si %	Ni %		Water Quenched (*b*)	Water Quenched and Stabilized (*c*)
Commercial						
0·07	0·44	0·24	36·8	1·9	0·9	1·1
Experimental						
0·02	0·09	0·01	36·0	0·8	0·1	0·0
0·10	0·12	0·08	36·1	1·6	0·1	0·0
0·15	0·08	0·17	36·0	1·5	0·1	0·0
0·25	0·05	0·20	36·6	1·4	0·0	1·0

(*a*) 830°C. (30 min.), furnace cooled. (*b*) 830°C. (30 min.) water quenched.
(*c*) Treatment (1) 830°C. (30 min.) water quenched; (2) 315°C. (1 hr.) air cooled; and (3) 95°C. (48 hr.) air cooled.

The effects of various heat treatments, on the average coefficient of thermal expansion (−40° to +40°C.), of five grades of Invar is shown in the table: carbon and

Loading-Coil Core Materials

Type of Material	Effective (*a*) Volume Permeability	Approximate Period of Commercial Manufacture	Principal Fields of Use
65-permeability, 4-mil, iron wire	36	1901-1924 1911-1927	Open Wire Lines Toll Cables
95-permeability, 4 mil, iron wire	52	1904-1911 1904-1916	Early Toll Cables Exchange Cables
Annealed, compressed, powdered iron	55	1916-1927 1916-1924	Exchange Cables Toll Cables
Unannealed, compressed, powdered iron	35	1918-1928 1924-1928	Toll Cables Exchange Cables
Compressed, powdered Permalloy	75	1927-1937 1927-1938	Exchange Cables Toll Cables
Compressed, powdered Molybdenum-Permalloy	125	1937- 1938-	Exchange Cables Toll Cables
Compressed, powdered Molybdenum-Permalloy	60	1948-	15 kc Cable Program Transmission
Non-magnetic	1	1920-	Carrier Loading Coils for Incidental Cables, Open-Wire Lines

(*a*) Initial permeability.

manganese both increase the value of the coefficient. In all grades water quenching from 830°C. results in a smaller coefficient than does furnace cooling from 830°C., an effect which is believed to be due to the fact that water quenching prevents precipitation of graphite from solid solution. Water quenching has the disadvantages that residual stress is introduced, and that dimensional instability, as manifested by irreversible length changes on ageing at or above room temperature, is increased. In order to achieve satisfactory stress relief and high dimensional stability, along with a low coefficient of thermal expansion, the following treatment was developed:

(1) 830°C., 30 min.; water quench;
(2) 315°C., 1 hour; air cool; and
(3) 95°C., 48-hour; air cool.

As shown in the Table on p. 134, this stabilizing treatment results in a lower coefficient of expansion than does furnace cooling, and it compares favourably with water quenching alone, provided that the carbon content of Invar does not exceed 0·15 per cent.

Nickel-Iron Alloys in Inductive Loading Devices in Telephones

T. SHAW: 'The Evolution of Inductive Loading for Bell System Telephone Facilities.' *Bell System Technical Jnl.*, 1951, vol. 30, Jan., pp. 149-204; Apr., pp. 447-72.

A detailed account of the contributions of inductive loading to the growth of the Bell Telephone system. Part I covers the beginnings of coil loading, Part II deals with loading for long-distance circuits, and Part III with loading for exchange-area cables.

The review forms the most complete story of the development yet published, and it is supported by an extensive *bibliography*, giving access to even fuller records of the various stages in progress. Attention is directed, in many instances, to the importance of improved loading materials, as factors in higher efficiency and more rapid and controllable communication. In this connexion, frequent reference is made to the Permalloy range of nickel-iron alloys: a table (see above) makes interesting comparison of the characteristics and uses of the respective grades.

Standard Methods for Analysis of Iron and Steel

See abstract on p. 137.

CAST IRON

Isothermal Transformations in Nickel-containing White Cast Iron

F. B. ROTE, G. A. CONGER and K. A. DELONGE: 'Isothermal Transformation Characteristics on Direct Cooling of Alloyed White Iron.' *Amer. Foundrymen's Soc., Preprint* 51-9, Apr., 1951; 13 pp.

The authors record the results of an investigation of the isothermal transformation characteristics of a white iron of the following nominal composition: total carbon 3·40, silicon 1·15, manganese 0·35, nickel 4·50, chromium 1·85, molybdenum 0·12, per cent. A complete T.T.T. diagram was determined from data obtained by hardness tests and microscopic examination of wedge-shaped castings, directly air-cooled from the mould to sub-eutectoid temperatures, for isothermal transformation.

Spheroidal-Graphite Cast Iron: Current Stage of Development

A. P. GAGNEBIN: 'The Industrial Status of Ductile Iron.' **Reprint from Mechanical Engineering*, 1951, vol. 73, Feb., pp. 101-8. Issued by International Nickel Co., Inc., 1951.

For abstract of this paper see *Nickel Bulletin*, 1951, vol. 24, No. 4, p. 80.

Machinability Tests on Spheroidal-Graphite Cast Irons

J. F. KAHLES, N. ZLATIN and R. B. KROPF: 'High Machinability and Productivity of Ductile Iron.' *Metal Progress*, 1951, vol. 59, Feb., pp. 238-42.

*Reprint issued by International Nickel Co., Inc., 1951.

Report of investigation of machining characteristics of five flake-graphite cast irons and five cast irons containing various percentages of spheroidal graphite: see table below. Tool-life in turning tests shows that machinability improves as the degree of ductility rises, as the amount of free ferrite increases, or as the associated Brinell hardness decreases. Particular attention is called to the observation that the annealed ductile irons can be cut at speeds as high as 1,000 ft. per min., with reasonable tool life. A further finding is that, at a given hardness level, the ductile irons are about 25 per cent. more machinable than flake-graphite irons.

The authors also emphasize the very considerable improvement which can be effected in the machinability of the ductile irons by production of a ferritic structure, e.g., by annealing. In that condition the irons still retain high mechanical strength (in the region of 70,000 p.s.i.: 31·25 tons per sq. in.), thus offering an engineering material of good quality which can be handled at high production rates.

Most of the ductile irons which have been produced to date are of the type showing spheroidal graphite in a pearlitic matrix, a form of structure which, although associated with high mechanical strength, does not provide optimum machinability. Since, however, many of the potential applications of ductile irons will be for parts where good machinability is a ruling consideration, on the grounds of high productivity rates, consideration has been given to the annealing treatment which will give best machinability without impairment of mechanical properties. The cycle recommended is heating at 1600°-1700°F. (870°-925°C.) for 30-60 minutes, followed by a 5-hour heating at 1275°F. (690°C.). The high-temperature treatment is designed to ensure rapid decomposition of any dendritic carbides which may be present, especially in sections of ¼ in. or below: the second treatment, at the lower temperature, has for its object the decomposition of pearlite to ferrite and spheroidal graphite.

Cast Irons for Machinability Study

Structure	C %	Mn %	P %	S %	Si %	Ni %	Other Elements %
FLAKE-GRAPHITE CAST IRON							
Acicular iron	2·78	1·03	0·12	0·064	2·30	2·11	0·32 Mo
Fine pearlite..	3·22	0·62	0·08	0·097	2·10	0·85	0·64 Cr
Coarse pearlite	3·17	1·10	0·10	0·108	2·44	—	—
Ferrite (annealed)*	3·47	0·35	0·05	0·133	1·62	—	—
SPHEROIDAL-GRAPHITE CAST IRON							
							Mg
20% ferrite (as cast) ..	3·33	0·45	0·11	0·018	2·66	1·65	0·078
60% ferrite (as cast) ..	3·41	0·42	0·09	0·014	2·82	0·81	0·073
60% ferrite (as cast) ..	3·82	0·23	0·082	0·018	3·04	1·13	0·082
97% ferrite*	2·79	0·53	0·09	0·014	2·76	1·59	0·071
100% ferrite*	3·69	0·27	0·045	0·014	2·64	1·15	0·060

*Annealing cycle: Heated to 1650°F. for 30 min., furnace cooled to 1275°F., and held there for 5 hours, air-cooled.

The effect of variation in times of heating, and of omission of the first stage of treatment, as affecting the final structure and associated machining qualities of the irons, are studied in this report. A curve illustrates the time required at 1650°F. (900°C.) to break up primary carbide in as-cast carbidic iron, and the time necessary at 1275°F. (690°C.) to transform pearlite into ferrite.

With regard to applications of irons so treated, the authors are of the opinion that a considerable potential demand exists. Irons in this condition would be particularly suitable for mass production of cylinder heads, pump bodies, manifolds, housings and other automotive parts, and the production of many components now generally made in high-strength irons

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would be materially accelerated by a turnover to ferritic ductile iron. In the heavy-machinery field, also, it is believed that the high modulus of the new irons, coupled with their other physical and mechanical properties and machinability, can advantageously be utilized in production of gears, pump impellers and other castings requiring the unusual combination of properties provided by ductile iron in the machinable condition.

Nickel-Alloy Cast Iron in Crankshafts

A. B. EVEREST: 'Cast Iron Crankshafts, with Special Reference to Acicular and Spheroidal-Graphite Cast Irons.' *Congrès International des Moteurs*, Paris, May, 1951; Group IV-1; 20 pp.

Some intrinsic characteristics of cast iron, and the development of cast crankshafts in general, are briefly reviewed as an introduction to more detailed consideration of two types of cast iron which are peculiarly suitable for this application.

Production economies which may be effected by adoption of cast iron for crankshafts are pointed out, reference is given to descriptions of production technique which have been published in England and in America, and the fields of application of cast-iron crankshafts are delimited.

Attention is then given to the importance, in connexion with this application of cast iron, of the improved properties consistently obtained in some of the newer grades of iron. One of the materials which have found wide acceptance for this purpose is an iron in which an acicular structure is produced by balanced additions of nickel and molybdenum. The tensile strength of this material is of the order of 25-35 tons per sq. in., and can be still further raised by heat-treatment. Other mechanical properties are correspondingly high, and the impact-resistance is at least twice that of the best pearlitic high-grade cast iron. The wear-resisting qualities of acicular cast iron are also good, and its hardness is relatively high, but, in spite of this latter feature, the castings are readily machinable.

The second type of cast iron which has recently become significant in relation to crankshaft application is the spheroidal-graphite type: representative structures of this iron are shown in the paper and the value of its improved properties are indicated. The properties of five types of crankshaft material are compared in a table showing mechanical properties, impact-resistance, fatigue-resistance, notch-sensitivity, and damping capacity. The comparison covers forged carbon steel (quenched and tempered), nickel-chromium-molybdenum steel (forged and heat-treated), high-duty cast iron to 20 tons min. tensile specification, acicular cast iron, and pearlitic spheroidal-graphite cast iron.

In the final section of the paper some account is given of service experience with acicular cast iron (including comparative production-cost data for Diesel-engine crankshafts in steel and cast iron). Developments to date with spheroidal-graphite cast iron are also reviewed. These indicate a promising field of application for the new iron as a crankshaft material, and in this connexion the author records that tests on spheroidal-graphite iron having an acicular matrix (developed by suitable additions of nickel and molybdenum) demonstrate that tensile strength of the order of 50-60 tons per sq. in. can be attained in such material, with other mechanical properties at a corresponding level.

Determination of Magnesium in Cast Iron

W. WESTWOOD and R. PRESSER: 'Chemical Determination of Magnesium in Cast Iron.' *Analyst*, 1951, vol. 76, Apr., pp. 191-9; disc., pp. 199-200.

In connexion with the development of spheroidal-graphite cast iron by means of magnesium treatment, a need has arisen for highly accurate estimation of magnesium. This paper describes a method developed in the laboratories of the British Cast Iron Research Association.

The procedure, of which full details are given, is based on dissolution of the sample in hydrochloric acid, extraction of most of the iron with *iso*propyl ether, removal of manganese and some of the remaining elements by electrolysis with a sodium amalgam cathode, formation of complex ions, with citric acid, of any remaining interfering elements, and double precipitation of the magnesium as phosphate. Zirconium interferes with the method described.

CONSTRUCTIONAL STEELS

Standard Methods for Analysis of Iron and Steel

BRIT. STANDARDS INSTN.: 'Methods for the Analysis of Iron and Steel.' *B.S.* 1121 series.

Part 19, 'Small Amounts of Soluble Silicon in Plain Carbon and Low-Alloy Steels and Irons (Absorptiometric Method).'

The sample is dissolved in dilute sulphuric acid and insoluble material is removed by filtration. The silicon is converted to silico-molybdate, which is then reduced to molybdenum blue by oxalic acid and ferrous sulphate, the resultant colour being measured photometrically.

Part 20. 'Tin in Highly Alloyed Steels (including High-Speed Steels).'

The method depends upon removal of the carbide residue from an initial solution of the steel in a non-oxidizing acid, followed by isolation of the tin as the sulphide, using molybdenum sulphide as a 'carrier' agent; solution of the sulphide; reduction of the tin to the bivalent condition with metallic aluminium in the presence of an antimony salt, and titration of the reduced tin with standard iodate.

Part 21. 'Aluminium Oxide in Permanent-Magnet Alloys.'

The materials for which this method of analysis are suitable contain aluminium 5-15, nickel 7-35, cobalt 10-30, copper 0·5-8, titanium 3 max., per cent., iron remainder.

The sample is treated with a mixture of methyl

alcohol and bromine, leaving aluminium oxide in the insoluble residue. After fusion of the residue with potassium bisulphate and extraction of the melt in dilute sulphuric acid, iron and titanium are separated by precipitation with cupferron. Aluminium is precipitated with 8-hydroxyquinoline and the compound is either weighed or titrated.

The range is up to 1·0 per cent. of aluminium oxide.

In all cases full details are given of special apparatus required, and of technique of analysis.

Isothermal Transformation Diagrams for Nickel-Alloy Steels

MOND NICKEL CO., LTD.: 'Isothermal Transformation Diagrams for Nickel Steels.' *Publn.* 428, 1951; 57 pp.

Isothermal transformation diagrams, initially proposed by Davenport and Bain in 1930 as a means of studying steels, show the time taken by a steel to transform isothermally, at sub-critical temperatures, from austenite to mixtures of ferrite and carbide. Subject to certain limitations, which are critically discussed in this publication, these diagrams can practically assist understanding of the effects produced in heat-treatment, and the control which should be maintained during such treatment. The interpretation of the diagrams, as an aid to production of optimum properties in heat-treated steels, is considered.

The opening section of the brochure describes methods of determination of the curves, and mode of presentation of the results. This is followed by a discussion of general features of isothermal transformation diagrams, notes on the effect of composition on transformation, the nature of the martensite reaction, retention of austenite and its effects, the influence of structure on mechanical properties, and the limitations of isothermal transformation diagrams. A supplementary section deals with cooling curves of oil-quenched and air-cooled bars of deep-hardening steel, included in view of their general usefulness in control of heat-treatment schedules. The extent to which these curves can be used in conjunction with isothermal transformation diagrams is indicated. The final section of the letterpress describes the essential features of some special heat-treatments based on isothermal transformation diagrams:—martempering (interrupted-quenching and time-quenching), austempering (to obtain intermediate structures), and isothermal annealing (used mainly to soften for machining or cold-forming operations).

The text is illustrated by a number of photomicrographs showing typical structures produced under various conditions of isothermal transformation.

A major section of the publication comprises a series of tables and diagrams showing composition and isothermal transformation characteristics of nickel-containing steels of the following B.S.En types:—12, 22, 23, 24, 25, 26, 28, 30, 30A, 30B, 100, 110, 111, 160.

The information given is based on determinations made in the laboratories of The Mond Nickel Company, and is supported by a selected *bibliography* of 35 items referring to some major literature of the subject.

An article based on this publication appears in *Metallurgia*, May, 1951, pp. 234-42; June, pp. 280-8.

Properties of Sintered Nickel Steels

F. BENESOVSKY: 'Sintered Nickel Steels.' *Powder Metallurgy Bull.*, 1951, vol. 6, Apr., pp. 18-21.

In the experiments described, iron powder produced by the Hametag process (50-50 mixture of powders of particle sizes −100 and −230 mesh) was mixed with 2, 4, 6, 8, 10, 12 and 14 per cent., respectively, of carbonyl nickel powder, and with 0·4 and 0·7 per cent. graphite powder. A graphite-free series having the same nickel levels was also made. From these mixed powders, flat tensile test bars were pressed at about 43 tons per sq. in. The specimens containing carbon were sintered for four hours at 1220°C., in closed graphite boats, in a muffle furnace, under dry hydrogen: the carbon-free alloys were sintered for a similar period at 1280°C. in iron boats. Both single- and double-pressing procedures were used: in the double-pressing cycles the specimens were pre-sintered for 30 minutes at 900°C., re-pressed at 57 tons per sq. in. and finally sintered under the above conditions.

Results, reported in tables and photomicrographs, show that—

(1) density increases with rise in nickel content: no marked effect of carbon was observed in this connexion;

(2) in carbon-free alloys, hardness increases almost linearly with increasing nickel content. In the steel specimens the 0·4 per cent. carbon series showed maxima in the hardness values at 10-12 per cent. nickel (360 and 420 Vickers, for single- and double-pressed steels, respectively). In the 0·7 per cent. carbon steels the maxima occurred at 8-10 per cent. nickel (390 and 455 for single- and double-pressed specimens, respectively). At the stage at which austenite occurs, hardness begins to fall with increasing nickel. It is pointed out that these values refer only to the surface properties, and that in the interior of the compacts structural phases of lower hardness and strength may occur;

(3) maxima corresponding to those observed in the hardness curves were found in the tensile tests. The highest value recorded was for double-pressed steels containing carbon 0·4, nickel 10, per cent. Elongation was markedly influenced by structure; the steels in the pearlitic range showed very high elongations; the martensitic steels were brittle, but on occurrence of austenite elongation again increased.

Boron-containing and other Low-Alloy Steels: U.S. Specifications

'New Steel Compositions to Conserve Critical Alloying Elements.' *Materials and Methods*, 1951, vol. 33, Apr., pp. 105, 107.

Five new grades of steel have been developed in U.S.A. to conserve manganese, nickel, chromium and molybdenum. The compositions, which, it is emphasized, should be considered as in only the early stages of production, are given below.

Grade	Chemical Composition Limits %					
	C	Mn	Si	Ni	Cr	Mo
Boron-containing Steels, 80BXX, 81BXX, and 94BXX						
80B20	0·17/0·23	0·45/0·70	0·20/0·35	0·20/0·40	0·15/0·35	0·08/0·15
80B25	0·21/0·28	0·50/0·75				
80B30	0·27/0·34	0·55/0·80				
80B35	0·32/0·39	0·65/0·95				
80B40	0·37/0·45					
80B45	0·42/0·50					
80B50	0·47/0·55	0·70/1·00			0·25/0·50	
80B55	0·50/0·60				0·30/0·55	
80B60	0·55/0·65				0·30/0·55	
81B35	0·32/0·39	0·70/1·00	0·20/0·35	0·20/0·40	0·30/0·55	0·08/0·15
81B40	0·37/0·45					
81B45	0·42/0·50				0·35/0·60	
81B50	0·47/0·55	0·75/1·05				
94B17	0·14/0·20	0·70/1·00	0·20/0·35	0·30/0·60	0·30/0·55	0·08/0·15
81XX Steels						
8115	0·13/0·19	0·70/1·00	0·20/0·35	0·20/0·40	0·30/0·55	0·08/0·15
8117	0·14/0·20					
8120	0·17/0·23					
8122	0·19/0·25					
8125	0·21/0·28					
8127	0·24/0·31					
8130	0·27/0·34					
8132	0·29/0·36					
8135	0·32/0·39					
8137	0·34/0·42					
8140	0·37/0·45					
8142	0·39/0·47					
8145	0·42/0·50					
8147	0·44/0·52					
8150	0·47/0·55	0·75/1·05			0·35/0·60	
8155	0·50/0·60					
8160	0·55/0·65					
Modified 86XX Steels						
Modified 8615	0·13/0·19	0·70/1·00	0·20/0·35	0·40/0·70	0·55/0·80	0·08/0·15
8617	0·14/0·20					
8620	0·17/0·23					
8622	0·19/0·25					
8625	0·21/0·28					
8627	0·24/0·31					
8630	0·27/0·34					
8632	0·29/0·36					
8635	0·32/0·39					
8637	0·34/0·42					
8640	0·37/0·45					
8642	0·39/0·47					
8645	0·42/0·50					
8647	0·44/0·52					
8650	0·47/0·55					
8655	0·50/0·60					
8660	0·55/0·65					

Note 1.—The phosphorus and sulphur limitations for each steelmaking process are as follows:—Basic electric furnace 0·025% max.
Basic open hearth 0·04 % ,,
Acid electric furnace 0·05 % ,,
Acid open hearth 0·05 % ,,

Note 2.—Minimum silicon limit for acid-open-hearth or acid-electric-furnace alloy steel is 0·15%.

Note 3.—Small quantities of copper are present in alloy steels but are not specified or required. This element is considered incidental and may be present in an amount not exceeding 0·35%.

Note 4.—The ranges and limits shown above apply to steel not exceeding 200 sq. in. in cross-sectional area, or 18 in. in width, or 10,000 lb. in weight per piece.

Investment Casting of Nickel-containing Steels: Study of Pre-Coats

See abstract on p. 128.

Nickel-Molybdenum Steel Tapered Roller Bearings

J. H. EVANS: 'Nickel-Molybdenum Steel used in the Manufacture of Tapered Roller Bearings.' *Alloy Metals Rev.*, 1951, vol. 8, Apr., pp. 2-7.

The majority of tapered roller bearings are made from a steel containing nickel 1·65-2·0, molybdenum 0·20-0·30, per cent., conforming to En 34 and S.A.E. 4620 specifications, or from a steel of this type modified to give specially balanced composition and controlled grain size, ensuring uniform hardenability of case and core.

The very stringent requirements laid down for steel for tapered roller bearings are reviewed, and investigations made by the Timken Roller Bearing Company, to develop the optimum combination of properties, are described.

A high degree of cleanliness in the steel is a primary essential, and as a first step towards assessing the core and case hardenabilities, much information was correlated on the influence of residual elements, e.g., chromium, and the manganese/chromium ratio, on the hardenability of 1 per cent. carbon nickel-molybdenum steel. A Jominy end-quench chart shown in the paper gives maximum values obtained in examination of some 150 production heats of the steel. Steels with carefully balanced ratios of carbon, chromium and manganese are stated to give, in 1-in. test bars, the properties shown in the table above.

	Yield Stress t.s.i.	Maximum Stress t.s.i.	Elongation %	Reduction Area %	Impact Ft.-lb.	Brinell Hardness
'As received', normalized ..	35·6	45·4	25·5	57·2	—	212
'As received', special structure	30·0	41·2	28·5	58·0	—	183
Hardened	40·6	62·4	22·0	49·6	60/63	285

Highly detailed study was also made of the method by which optimum machinability could be obtained in this steel, and it was found that in order to ensure consistent cutting characteristics and close dimensional control, both in machining and after heat treatment, variations in hardness and in metallographic structure must be reduced to a minimum. Further experiments showed that the best machining properties resulted from a controlled rate of cooling after hot-rolling. Where facilities exist, this can be effected by running the tubes direct from the mill, at full temperature, into shallow cooling pits or troughs, covering, and allowing to cool to below 600°C. Alternatively, when mill conditions render this treatment difficult, the tubes can be air cooled from hot rolling, re-heated to about 1000°C. and cooled at a controlled rate through the critical range. The structure so obtained is illustrated, and machining tests are reported to indicate its advantages. These have been so great that in the Timken plant every endeavour is being made to standardize on such structure for all incoming nickel-molybdenum steel, whether in the form of tubes or forgings.

The roller-bearing components are either pack- or gas-carburized. Gas carburizing is regularly used, and the town's gas used as diluent is first conditioned by passing through heated charcoal or carburizing compounds, and then energized by addition of propane or butane, immediately before entering the furnace. Temperature of treatment is 900-915°C., and standard practice is to allow a diffusion period of approximately one-half of the actual gas time, after which the components are directly oil quenched. All parts, whether core-refined or oil-quenched from gas carburizing, are re-heated in an accurately controlled electric furnace and again oil-quenched from 780°-795°C., to harden the case. Residual hardening stresses are relieved by tempering at 165°C., giving a final hardness of Rockwell C. 58-65.

HEAT- AND CORROSION-RESISTING ALLOYS

Specifications for Heat- and Corrosion-Resisting Alloys

ALLOY CASTING INST.: 'A.C.I. Standard Designations and Chemical Composition Ranges for Heat- and Corrosion-Resistant Castings.' 1951 *Edn., published by the Institute.*

The list covers the following grades of alloys standardized by the Institute: CA, CB, CC, CE, CF, CH, CK, CN; HC, HD, HE, HF, HH, HI, HK, HL, HT, HU, HW, HX.

Among the revisions in the 1951 edition is the provision for use of ferro-niobium-tantalum as an alternative to ferro-niobium in the 18-8 stabilized type of casting alloy. The provision is for Nb+Ta 10×C min., 1·35 per cent. max. Two grades have been dropped from the list of standard alloys, in view of the relatively small use of such compositions in industry: these are CG-12 (chromium 20-23, nickel 10-13, carbon 0·12 max., per cent.) and CH-10 (chromium 22-26, nickel 12-15, carbon 0·10 max., per cent.).

A useful innovation in the new list is the inclusion of type numbers for corresponding wrought alloys, which, with certain reservations indicated in the publication, may be used to correlate specifications for cast and wrought materials.

The Significance of Silicon in Nickel-containing High-Temperature Alloys

H. J. GOLDSCHMIDT: 'The Importance of Silicon in Niobium-bearing Steels and Alloys.' *Metallurgia*, 1951, vol. 43, Apr., pp. 157-60.

Realization of the potential value of niobium-bearing steels and alloys has been one of the outstanding features in the development of high-temperature materials for gas-turbine components and other applications. Reference is made to initial use of substantial amounts of niobium in Jessop G.18B (see paper by OLIVER and HARRIS abstracted on page 118 of this issue of *The Nickel Bulletin*), and consideration of the literature indicates the large number of other steels and alloys in which this element is an essential constituent.

The present paper, based on high-temperature research in the Jessop laboratories, draws attention to the important rôle of silicon used in conjunction with niobium. An account is given of X-ray examination of electrolytic extracts from various high-temperature steels in which the two elements are present, particular attention being directed to G.18B and R.20.

In these extracts a ternary iron-niobium silicide occurs, having the approximate formula $Fe_4Nb_5Si_3$; the same phase is found in silicon-rich ferro-niobium. The information derived from the research described makes it possible to explain the constitution of niobium- and silicon-bearing steels as a collection of carbides, silicides and intermetallic compounds (iron-niobides and tungstides), in an austenitic matrix. It is considered that, in heat-resisting materials containing niobium, silicon plays a rôle comparable to that of carbon: it is also shown that, to some extent, the silicide- and carbide-forming tendencies are competitive. Formation of the silicide, or its elimination, may be critically controlled by slight changes in the balance of the alloying elements (e.g., the niobium/silicon ratio), as well as by heat-treatment.

The rôle of silicon is not restricted to this type of steel, but has significance also in relation to the possible use of silicides in hard metals, in conjunction with, or in replacement of, carbides. The practical value of silicon would lie—

(1) in the inherent hardness of the silicides, although, like carbides, they are brittle;

(2) in their potential function of hardening the matrix when in incipient precipitation;

(3) in their ability to produce a thin protective surface film of silica or silicates, which would be operative at high temperatures; and

(4) in their better resistance to atmospheres in which carbides suffer decarburization.

The author considers it probable that niobium is not an isolated element encouraging silicide formation, but that the other elements of Groups IV and V (vanadium, tantalum, titanium, zirconium and hafnium) may also act in the same manner. The possible value of a molybdenum silicide should also be borne in mind.

Investment Casting of Nickel-containing Materials: Study of Pre-Coats

See abstract on p. 128.

Hot-Twist Ductility Tests on Austenitic Nickel-Chromium Steels

F. K. BLOOM, W. C. CLARKE and P. A. JENNINGS: 'Relation of Structure of Stainless Steel to Hot Ductility.' *Metal Progress*, 1951, vol. 59, Feb., pp. 250-6.

A hot-twist test for determination of ductility was first proposed by Sauveur in 1920, and its application in assessing the optimum temperature for hot piercing and forging was described by IHRIG, and by CLARK and RUSS, in 1944 and 1945, respectively.

The test consists essentially in inserting a round bar of uniform dimensions through a tubular furnace, bringing the portion in the furnace to the test temperature, clamping one end of the bar, and twisting the other end. The number of twists required to fracture the hot metal is the measure of its ductility; in some cases torque is also determined. Limitations due to temperature gradient between the ends and the centre portion to some extent affect the accuracy of the test, but it has been found useful as a rapid and simple method of evaluating the approximate workability of materials at various temperatures.

Clark and Russ suggested that each steel possesses a critical temperature, as assessed by hot-twist tests, and that above such temperature ductility will progressively decrease. They consider this critical temperature to be the equicohesive temperature of the respective steels, for the particular rate of strain involved. The present authors believe, however, that, at least in the case of stainless steels, the maxima in the ductility-temperature curves are more rationally explicable as associated with alteration in the microstructure of the steels with rise in temperature. Such explanation would account for cases in which the first maximum is followed by a second increase in ductility at a higher temperature, a phenomenon which cannot be accounted for by the Clark and Russ theory.

The present paper records a series of hot-twist tests on typical high-chromium and austenitic nickel-chromium steels of various compositions, in which ductility ratings are correlated with examination of microstructure of steels brine-quenched from the temperature at which ductility tests were made. From the considerable amount of experimental data reported, it is concluded that structure at the temperature of twist has a clearly marked influence on ductility. Austenite and ferrite, when present together, appear to have a more deleterious effect on ductility than when the predominant phase for a given composition is present alone. Thus, when the critical temperature for a given steel is passed, ductility changes sharply, becoming poorer if the material passes into a two-phase region, and better if it enters a single-phase region.

In plain-chromium steels, ferrite appears to be more ductile at a given temperature than austenite. In austenitic chromium-nickel steels, appearance of delta ferrite in the structure is harmful to hot ductility. This effect may be overcome, or substantially suppressed, by suitable balancing of ferrite- and austenite-producing elements in the steel. Molybdenum tends to cause deterioration in hot ductility, and the dis-

parity between molybdenum-free and molybdenum-containing austenitic steels is increased at the stage at which duplex structure appears, for example, in an 18-12-Mo steel. Anomalously high hot ductility was observed in a 26 per cent. chromium steel of purely ferritic structure at 2450°F. (1342°C.). The authors advance a tentative theory to explain this phenomenon.

Machining of Nimonic Alloys

HENRY WIGGIN AND CO., LTD.: 'Notes on Machining the Nimonic Series of Alloys.' **Publn.* 343A; 1951. Revised reprint of publication issued in 1950; see *Nickel Bulletin*, 1950, vol. 23, No. 6, p. 109.

A fully illustrated survey of current practice adopted by the principal users of Nimonic alloys, supplemented by a list of makers of proprietary articles which have proved satisfactory in processing this group of alloys.

Crystal Structure of Chromium Carbide in Austenitic Steels

J. F. BROWN and D. CLARK: 'Identification and Crystal Habit of Chromium Carbide, $Cr_{23}C_6$, as Determined by Electron Diffraction.' *Nature*, 1951, vol. 167, May 5, p. 728.

The note describes observations made on residues obtained, by electrolytic extraction, from a 25-20 chromium-nickel steel. The results confirm conclusions drawn by MAHLA and NIELSEN (*Amer. Soc. Metals, Preprint* 16, Oct., 1950) that the growth of chromium carbide in certain steels is controlled by the [111] lattice planes.

Influence of Selenium Additions on the Properties of Stainless Steel

R. J. WILCOX: 'Improving Stainless Quality by the Use of Minor Selenium Additions.' *Alloy Casting Bull.*, 1951, Mar., pp. 1-2, 5-6.

The paper reports investigations carried out under the joint auspices of the Alloy Casting Institute and the Michigan Steel Casting Company, which have resulted in commercial practice described by the author in a paper to the American Institute of Mining and Metallurgical Engineers (see *Nickel Bulletin*, 1951, vol. 24, No. 1, pp. 18-19). In the present report particulars are given of tests made to ascertain the effect of the selenium additions (primarily made to eliminate porosity), on the mechanical and corrosion-resisting properties of 18-8, 18-8-Mo and 19-29-Mo-Cu chromium-nickel steel castings. Corrosion tests comprised exposure in 65 per cent. boiling nitric acid, boiling sulphuric acid and salt-spray. The results, details of which are given, indicate that the small additions of selenium required to eliminate porosity (of the order of 0·01-0·05 per cent.) are without detrimental effect on either mechanical strength or corrosion-resisting quality. The authors suggest that, in view of the current shortage of selenium, tellurium, which has a degasifying effect similar to that of selenium, might be used as a substitute. The editor, however, adds the following warning note: 'Recent reports of cracking of castings made of tellurium-treated alloys, and of the disagreeable effect of working with tellurium (e.g., offensive odour, halitosis), throw considerable doubt on the feasibility of substituting tellurium for selenium.'

Cleaning and Finishing Stainless Steels

T. C. DU MOND: 'Cleaning and Finishing Stainless Steels.' *Materials and Methods Manual No.* 69. *Materials and Methods*, 1951, vol. 33, Apr., pp. 93-104.

One of the regular series of 'manuals', embodying condensed, but practically useful, information culled from a number of sources. The various mill finishes in which stainless steels are normally supplied are reviewed, as an introduction to sections in which recommended practice is summarized. Methods of cleaning, pickling and descaling are described and grinding, polishing and buffing procedure is outlined, with a table showing the sequence of operations and materials used at the respective stages. Brief reference is made to current methods of passivation and of industrial electropolishing, and plating, colouring and etching procedures suitable for the stainless steels are mentioned.

Resistance of Nickel-containing Materials to Copper Sulphate

'Materials of Construction vs. Copper Sulphate.' *Chemical Engineering*, 1951, vol. 58, Apr., pp. 206, 208, 210, 212-14, 216.

In this section of the 'Corrosion Forum' series, the following materials are considered in relation to their behaviour in contact with copper-sulphate solutions: carbon, high-silicon irons, Worthite, nickel and nickel alloys, glass, stainless steels, Durimet 20, Chlorimet alloys, silicones, aluminium, coatings, rubber, wood, cements, tantalum, iron and steel, lead, and Hastelloy alloys.

Worthite is highly resistant to all concentrations of copper sulphate up to boiling temperature. It is very widely used for pumps and other parts in copper-refining plants and in copper-sulphate manufacturing operations. This material also finds some application in pickling plants and other installations handling copper sulphate/sulphuric acid solutions. Hot solutions of this type tend to cause intergranular corrosion: it is therefore essential that Worthite be put into service in a fully stabilized condition, which can be produced by heating at 2050°-2100°F. (1120°-1150°C.), followed by rapid cooling.

Nickel and Nickel Alloys

Monel has useful resistance to air-free cuprous sulphate solutions of most concentrations, at temperatures up to boiling but may be rapidly attacked by aerated solutions or solutions containing appreciable amounts of cupric sulphate.

Inconel is resistant to cupric acid solutions at moderate temperatures, but not up to boiling point. Nickel is less resistant than Monel to cuprous sulphate solutions, and not so good as Inconel in contact with cupric sulphate. It is therefore seldom used in this connexion. Main applications of Monel are for handling insecticidal copper-sulphate sprays and for

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pickling baskets in the sulphuric-acid pickling of copper and brass. Inconel is used for parts of filters and other equipment in the processing of copper-sulphate sludges in metal refining.

Stainless Steel

Copper sulphate is not injurious to the stainless steels, and solutions of any concentration, at any temperature, can safely be handled. Type 304 electroplating tanks for copper-sulphate electrolytes, and vat containers for copper sulphate employed as mordant in dyeing, are among the most commonly used types of equipment.

Durimet 20

This material shows good resistance to cuprous sulphate and to mixtures of cuprous sulphate and sulphuric acid, provided that conditions are not reducing. Equipment made from Durimet 20 is finding wide application for handling copper-sulphate/sulphuric-acid mixtures; typical examples are given.

Chlorimet Alloys

These alloys will give entirely satisfactory service in most copper-sulphate solutions, but, since less expensive alloys and the stainless steels provide equally good resistance in most conditions, the use of the Chlorimet alloys in this connexion is not extensive.

Hastelloy Alloys

The nickel-molybdenum-base grades offer excellent resistance to pure copper-sulphate solutions, over a wide range of concentration and temperature. They have also given good service in contact with many of the commercial solutions in which the sulphate is accompanied by sulphuric acid. Some specific examples of the uses of Hastelloy 'C' are quoted.

Tantalum as Stabilizer in Austenitic Nickel-Chromium Steels

R. D. THOMAS: 'Tantalum Partly Replaces Columbium (Niobium) Content of Electrodes.' *Iron Age*, 1951, vol. 167, Apr. 5, pp. 109-11.

Ferro-niobium containing about 55 per cent. niobium, 5 per cent. tantalum and 40 per cent. iron has for many years been used as the source of niobium embodied in the coating applied to 20-10 chromium-nickel steel electrodes. Due to the current shortage of niobium, a new type of ferro-alloy is now being produced, containing about 40 per cent. niobium, 20 per cent. tantalum and 40 per cent. iron. Relative recoveries of niobium with the two types of electrode are such that approximately 8 per cent. more ferro-tantalum-niobium of the second type is required.

This paper describes tests made on specimens of Type 347 weld metal having three different levels of niobium + tantalum, and on weld metal from two electrodes containing no stabilizing additions, one of which had core wire of normal carbon content, while the wire of the other was of extra-low-carbon type.

Room-temperature tests were almost identical on all the specimens; stress-rupture tests at 1200°F. (648°C.) showed slightly higher values for the 347 type, except in a short-time tensile test: all the stress-rupture values were well above those published for wrought material.

Intergranular-corrosion tests (Huey nitric-acid, Strauss acidified-copper-sulphate, and hydrofluoric/nitric-acid methods) indicated that tantalum has no effect on the rate of corrosion of all-weld metal specimens. Crack-sensitivity tests also established the interchangeability of Type 347 electrodes, whether manufactured with standard ferro-niobium or ferro-tantalum-niobium. Comparison of corrosion-test results on extra-low-carbon (Type 308) weld metal, with tests on stabilized weld metal, emphasizes that in many cases the E.L.C. electrodes can safely be used, thus effecting conservation of the strategic elements, niobium and tantalum.

See also—

W. O. BINDER: 'Interchangeability of Cb and Ta in Type 347 Stainless.' *Metal Progress*, 1951, vol. 59, pp. 219-27.

This paper reports a highly detailed study of the effects, on properties and welding quality, of substitution of tantalum for niobium in Type 347 steel. Intergranular-corrosion tests (in the three solutions mentioned in the previous abstract), high-temperature exposure tests, and welding experiments are reported, together with determinations of the room-temperature and short-time high-temperature mechanical properties of niobium-stabilized and tantalum-niobium-stabilized steels of 18-8 type.

The conclusions are identical with those drawn by the author of the previous paper.

Nickel-containing Corrosion-Resisting Materials in By-Product Coke Plant

C. F. POGACAR and E. A. TICE: 'Corrosion Problems in the Modern By-Product Plant.' *Corrosion*, 1951, vol. 7, Mar., pp. 76-84; Apr., p. 128.

This paper discusses the use of corrosion-resisting materials in the three sections of a coke plant: (1) the coal-handling section; (2) the ovens, with their coke-handling facilities; and (3) the by-product plant. All the test data presented were obtained by installation of spool-test racks in equipment operating under normal large-scale conditions, and may therefore be considered truly representative.

(1) *Coal-Handling Plant*

The structural steel in this section is usually protected by paints, and not many 'special' materials are used. Low-alloy high-strength steels may, however, be used to advantage for roofing and other applications. A case is quoted in which a low-alloy nickel-chromium-copper steel proved markedly superior to carbon steel for roofing over a coke wharf. The main application of corrosion- and abrasion-resisting materials in the coal plant is for chutes, in which both Monel and stainless steels have been used to some extent. A chart in the paper shows results of comparative wear tests on various ferrous and non-ferrous materials working as parts of a coke chute. The superior resistance of the stainless steels and Monel is clearly demonstrated.

(2) *The Ovens*

Less corrosion is found on metals exposed to air

round the actual ovens than would be expected, due, it is believed, to the fact that temperatures are sufficiently high to keep the parts dry except during continuous rains. Coatings of tar formed by condensation also have a protective effect. The majority of the corrosion occurring in this section of the plant is in connexion with the coke-quenching operations. Corrosivity of the water employed varies according to the locality of the plant, but data reported in the paper from a station using brackish water for quenching indicate that small additions of alloy elements to steel effect little improvement in corrosion resistance. In some cases high-alloy materials of the stainless steel, Inconel or Monel types give good resistance to corrosion, but in this service pitting is apt to occur. In stations using spray fluids containing calcium chloride stainless steel has given good service.

(3) *By-Product Plant*

From the point of view of corrosion-resisting materials, this is the most critical part of the plant, and calls for careful selection of materials of construction. The authors give consideration to conditions obtaining in the gas-cooling section, in which large amounts of ammonia are used. Reference is made to a plant at which the ammonia liquor is cooled by means of brackish water cascading over banks of pipes. Tests made to determine the most suitable material for this service indicated that copper-base alloys do not show good resistance, but that Monel, 70-30 cupro-nickel and Admiralty brass warrant further consideration. Use of Monel for the brackish-water spray pipe is definitely indicated, and one plant is reported to be experimenting with this alloy as replacement for galvanized piping.

Following description of conditions in the exhausters and the tar precipitators, a detailed account is given of experience in the sulphate saturators. Within the past eight years the use of materials other than lead, for saturator equipment, has been a major development, and both Monel and stainless steel (Type 316) are being successfully employed. The use of these two materials has made possible improvements in design which would have been out of question with lead-lined equipment. Charts show behaviour of Monel, stainless steels and other materials in various sections of the ammonium-sulphate plant, and the data thus obtained are confirmed by service experience of longer duration. Pumps, valves, centrifuge baskets, piping and filters are among the items for which Monel and/or stainless steel are in increasing use. Further tables and figures in the paper show comparative behaviour of nickel alloys, stainless steels and other materials, in conditions obtaining in the ammonia-distillation process, in a crude benzol washer in which a water dilution follows the acid wash, and in a washer in which sodium-hydroxide neutralization directly follows the acid wash.

A further contribution by the authors, made after actual delivery of the paper, consists of (1) tables showing corrosion-resistance of Inconel, stainless steels, nickel, Monel and Ni-Resist in a typical ammonia still (specimens exposed in three critical positions), and (2) further data on behaviour in plant used in the light-oil acid-washing process, in which water dilution is involved, thereby enhancing corrosivity of the conditions. In the first case carbon steel shows a usefully low rate of corrosion, while the stainless steels, nickel and the high-nickel alloys are susceptible to pitting. In the acid-washing plant the superior resistance of lead becomes obvious, but the low mechanical properties of this material are a disadvantage. Of the other materials tested, only four appear to warrant consideration: Carpenter 20, Monel, 10 per cent. aluminium bronze and silicon bronze, and even these materials show corrosion rates so high that the unit would require to be designed with sufficient thickness to allow for considerable loss.

Corrosion-Resisting Materials in Marine Engineering

L. W. JOHNSON and E. J. BRADBURY: 'Corrosion-Resistant Materials.' **Reprint, from Trans. Inst. Marine Engineers*, 1951, vol. 63, of paper read before the Institute, Feb. 13, 1951, and discussion; 22 pp.

This paper is in three sections, the scope of which is briefly indicated below.

I. *Theoretical Aspects of Corrosion.* The nature of direct chemical attack and electrochemical attack is defined, and a table shows the galvanic series of metals and alloys, indicating the tendencies of the respective materials to set up galvanic or electrolytic cells. The type of electrolytic corrosion cell liable to be set up in the presence of scale, corrosion product or protective film is illustrated and the possibility of corrosion occurring under stagnant conditions, e.g., in crevices and cracks, is considered.

Particular corrosion phenomena are reviewed under the headings of pitting, dezincification, intergranular attack, stress corrosion, corrosion fatigue and impingement attack. The causes and nature of the various forms of attack, and the types of resulting deterioration, are discussed, with particular reference to conditions likely to arise in marine service.

II. *Corrosive Media Encountered in Marine Engineering*

The principal corrosive media encountered in marine engineering are (*a*) fuels and the products of their combustion; (*b*) boiler water and steam; (*c*) sea water; and (*d*) the atmosphere. The form of attack imposed by each of these corrodents is discussed.

(*a*) Attention is directed to the corrosive effect of sulphur compounds occurring with coal and fuel-oil firing, and to the deterioration which may be caused by the ash formed. Analyses of ashes of fuel oils from various sources are tabulated and mention is made of the significance of the vanadium-pentoxide content of the ash as a factor in corrosive attack.

(*b*) The influence of the main contaminants which may be present in water is reviewed: oxygen, acids, alkalis, and calcium and magnesium salts. A graph shows typical attack on steel (at 310°C.) of water of varying degrees of acidity and alkalinity.

(*c*) Typical analyses of sea waters from two locations are given, to indicate the wide variation which may occur, but it is noted that, apart from water of highly contaminated types, sea waters in various localities, and of widely different compositions, have been found

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to show little difference in their corrosive attack on metals and alloys.

(*d*) The data presented indicate that marine atmospheric attack may vary widely from one locality to another.

III. *Corrosion Behaviour and Physical Properties of Various Metallic Materials*

In this, the main part of the paper, a large amount of tabular and other data is presented, relative to both non-ferrous and ferrous materials which are of interest in various branches of marine engineering.

A. Non-Ferrous Alloys

Six classes are considered: *copper; copper-zinc alloys; copper-tin and copper-aluminium alloys; copper-base alloys* (for heat-exchanger and other tubing); *nickel-base alloys; aluminium alloys.*

Tables show relative corrosion-resistance of various *copper alloys* subjected to different types of attack by sea water. The physical and mechanical properties of the alloys are also discussed, and the characteristics of the individual types are considered at some length, as indicating their suitability for use in various branches of marine engineering. Among the features of recent progress to which special attention is directed are the newer grades of cupro-nickel condenser-tube alloys, containing controlled percentages of iron.

In reviewing the applications of *nickel-base* alloys in this field, reference is made to the combination of mechanical properties and corrosion- and erosion-resistance which has led to the widespread use of Monel in various types of marine component working in contact with sea or fresh water, or with steam. High-nickel alloys are also of increasing interest in connexion with the introduction of gas-turbine propulsion for ships. For further information on the properties and potential applications of these materials attention is directed to the papers contributed to the Symposium on High-Temperature Steels and Alloys for Gas Turbines recently convened by the Iron and Steel Institute: see abstracts of papers on pp. 116-128 of this issue of *The Nickel Bulletin.*

Compositions and properties of *aluminium-base alloys* used in marine engineering are listed, and the nature of the sea-water corrosion-resistance inherent in such materials is briefly discussed. Sources of more detailed information on this group of alloys are indicated.

B. Ferrous Materials

Typical compositions, properties, and, where possible, British Standard specifications, are tabulated for the main groups of *chromium and chromium-nickel corrosion- and heat-resisting steels*, with an indication of their suitability for marine-engineering applications. Chromium-molybdenum heat-resisting grades are also considered. Some reference is made to established uses, e.g., chromium-nickel-tungsten steel (En 54; D.T.D. 49B) for valves, and heat-resisting austenitic steels in steam-turbine blading, a subject which was covered in some detail in a paper by Monypenny read before the Institute in 1945.

In the *cast iron* group the most important material from the marine engineer's point of view is Ni-Resist, the nickel-copper-chromium cast iron which shows good resistance to rusting, scaling at elevated temperatures, and growth. Its properties are given in the paper.

C. Coatings

In this connexion attention is directed to the use of relatively heavy metal coatings, and data are quoted showing the high degree of corrosion-fatigue-resistance obtainable, for example, in shafts of heavy-nickel-plated mild steel. Brief reference is also made to other types of coating: Sherardizing, calorizing, chromizing, metal-spraying, and cladding.

The information given in the paper is supported by a *bibliography* of 42 references.

Corrosion-Resisting Materials in Corn-Refinery Plant

R. W. FLOURNOY: 'Corrosion-Resistant Equipment for the Corn-Refining Industry.' *Corrosion*, 1951, vol. 7, Apr., pp. 129-33; disc., p. 133.

Corrosive environments existing in corn-refining plant arise from (1) the use of sulphur dioxide and sulphurous acid in the steeping of corn and during wet milling and separation processes; (2) the use of hydrochloric acid or sulphuric acid in dilute solutions, in the hydrolysis of starch slurries, to produce corn syrup and dextrose; (3) agents employed in production of acid and chemically modified starch or dextrine; (4) the presence of corn-oil fatty acids. A flow sheet illustrates the stages at which the respective conditions arise, and a series of tables reports results of laboratory and plant tests in which metallic materials were exposed to test conditions representative of those obtaining in large-scale plant. The materials exposed included a range of stainless steels, Inconel, cupro-nickel alloys, Monel, nickel, copper, various bronzes and brasses, and, in some cases, mild steel, cast iron and aluminium.

From the data obtained, the following summary is made:—

'*Sulphur-Dioxide Absorption Tower*

A wrought stainless No. 20 alloy was the only alloy tested which indicated satisfactory service in this sulphurous acid atmosphere. Wood, acid-proof brick and stoneware are used in plant practice.

'*Filtrates from Rotary Starch Filters*

Stainless steel Types 317, 318 and 316 indicated satisfactory service for starch wash filtrates. Stainless steel Type 304 failed in service as a filter bed after approximately six months' service. Crevice-type pitting was the primary cause of failure in this material.

'*Gluten-Slurry Blender*

Stainless steel Types 317, 310, 304, 347, aluminium (commercial purity), copper, yellow brass (70 copper, 30 zinc), silicon bronze and aluminium bronze indicated satisfactory service for gluten slurry. Stainless steel Type 316 and aluminium bronze have given satisfactory service as bowls in gluten slurry centrifuges. Rubber- and ceramic-lined valves used for throttling of gluten slurry failed in less than a month of service, due to loss of the lining by erosion.

'*Steepwater Evaporators*

Stainless steel Types 317, 316, 310, 304 and 347 indicated satisfactory service for steepwater evaporators. In plant practice, cast iron evaporator shells fail in two to five years of operation. Copper tubes in evaporators last between two and five years. Seamless stainless steel Type 304 tubes last between five

and ten years, but welded tubes give much shorter life. Welded stainless steel Type 316 tubes have been in service for two years with no indications of failure. Stainless steel Type 316 linings and tube sheets have given excellent service to date.

'*Dextrose Converters*

Some cast stainless steels and several alloys high in chromium, nickel and molybdenum indicated satisfactory service (with exceptions for crevice-type pitting) for the liquid and vapour phase of dextrose converters. Valves and pumps made from these alloys have shown good service life. A Ni-Resist valve (body) with stainless steel Type 316 seating surfaces has been in service on a dextrose converter liquor inlet for seventeen months with no evidence of corrosion. Acid-resistant bronze and aluminium-bronze valves give fair service in converter lines but are not as satisfactory as some of the high-chromium-nickel-molybdenum steels. Gate valves with stainless steel Type 316 seating surfaces cannot be operated under converter pressures. Galling of the seating surfaces leads to early failures.

'*Ion-Exchanged Corn-Syrup Liquors*

Stainless steel Types 317, 316, 304 and aluminium bronze indicated satisfactory corrosion resistance to this environment. Cast-iron body valves fail in a few months service in this environment.

'*Feed Drier Vapour Duct*

Stainless steel Types 318 and 316 (0·03 per cent. carbon max.) were the only materials tested which indicated satisfactory service life for this drier duct. Cast iron sections show rapid corrosion within a few years.'

Standard Methods for Analysis of Iron and Steel

See abstract on p. 137.

Tungsten Alloys Produced by Infiltration

R. PALME: 'Production of Tungsten Alloys of High Density by the Infiltration Process.' *Powder Metallurgy Bull.*, 1951, vol. 6, pp. 32-4.

Sintered alloys of tungsten base, containing 4-6 per cent. of nickel and 2-4 per cent. of copper, have for some years been used under the designation 'Heavy Metal', in applications requiring high specific gravity, e.g., in balance weights, and as shields against X-rays and radioactive radiations. Such alloys are produced by sintering finely ground powders of the component metals at 1400°-1500°C. A low-melting copper-nickel-tungsten phase is formed during sintering, and compacts of almost theoretical density are obtained.

The present paper describes an infiltration technique, recently developed at the Metallwerk Plansee, Reutte, Tyrol, by which a density of more than 18 g./cm^3 is secured. In this process a tungsten skeleton is infiltrated with a tungsten-nickel alloy, advantage being taken of the fact that at 1510°C. nickel is capable of dissolving about 52 per cent. of tungsten. This method not only makes it possible to incorporate a larger amount of tungsten in the final alloy (thereby considerably increasing its density), but it also prevents attack of the tungsten skeleton by the addition alloy, since the latter is already substantially saturated with tungsten when it penetrates the skeleton. The technique is illustrated by a description of stages in production using a infiltrant mixture containing tungsten 52, nickel 48, per cent. The final composites, typical structures of which are illustrated, show a Brinell hardness of the order of 330 kg/mm^2, with satisfactory machining qualities.

C. G. GOETZEL: 'Tungsten-Reinforced Superalloys.' *ibid.*, pp. 35-40.

This paper also deals with the use of the infiltration technique, reporting its application to the impregnation of tungsten and tungsten-chromium alloys with Nichrome V (nickel-chromium alloy), Hastelloy C (nickel-chromium-iron-molybdenum alloy), and some cobalt-base alloys. Details are given of the production and infiltration methods employed.

The composite specimens were microscopically examined (structure of a nickel-chromium-impregnated tungsten is illustrated), and were subjected to tests to determine specific gravity, hardness, and modulus of rupture at room temperature, and short-time transverse rupture strength at 1800°F. (985°C.) and above. Oxidation tests were also made at 1800°C. and some higher temperatures.

It was found that low-porosity skeletons of pure tungsten could be readily infiltrated with cobalt- and nickel-base alloys; comparatively sound structures were obtained. At room temperature the composite was strong, though of high specific gravity, but when exposed in still air at 1800°F. progressive oxidation occurred. Composite structures obtained by infiltration of tungsten skeletons with Stellite alloys, Vitallium, and, especially, Nichrome V and Hastelloy C, were, in general, found to show mechanical properties and chemical stability superior to those of molybdenum-base compacts of comparable type. The combination of properties obtainable in the tungsten-base materials was, however, below the specification requirements for power-engine applications. Surface impregnation of the composites with chromium also failed to raise the properties to the standard required for such use.

Alloying of tungsten with chromium, in various ratios up to 35 per cent., prior to forming of the skeleton and infiltration with the alloys named, had a pronounced effect on both processing and properties. Production of fully infiltrated and sound structures became increasingly difficult with rise in chromium content, which was also accompanied by increasing brittleness and fall in mechanical strength, both at room temperature and at 1800°F. The presence of chromium in the skeleton did, however, effect considerable improvement in resistance to oxidation; addition of 25 per cent. of chromium produced in the Nichrome-filtrated material a degree of oxidation-resistance equal to that of bulk Nichrome V.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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